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Aircraft measurements in the GARP Atlantic Tropical Experiment

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Summary

Measurements made by a research aircraft on three flights in the tropics are described. The measurements were made in a cloud cluster, in convective cloud associated with the intertropical convergence zone, and in suppressed boundary-layer conditions. The primary aim of the paper is not to investigate the overall dynamics of these systems, but rather to demonstrate how well the data from the aircraft can be combined with those from ship-borne weather radar and from tethered and radiosonde balloons, and with data from other aircraft, to provide an excellent quantitative description of the phenomena.

Introduction

The aim of this paper is to describe how measurements from a modern research aircraft can be used for the exposition of a wide range of meteorological phenomena which are much less clearly described by the application of measurements from only the more conventional sources of data, such as radiosondes, ground-based weather radar, and tethered balloons. This is done by co-ordinating data from one such aircraft with those from other aircraft and the sources mentioned above for three days of the GARP† Atlantic Tropical Experiment (GATE).

The field phase of GATE lasted from June to September 1974. The observational program completed during this period was of unprecedented size and complexity, involving the provision and effective deployment of an international fleet of 12 research aircraft over the eastern tropical Atlantic and of 39 specially equipped ships from the West African coast to the eastern coast of South America; additional observations were secured from a specially launched satellite and from land stations.

The massive volume of data collected by these 'platforms' is being used by scientists to answer questions on the structure and evolution of tropical weather systems and interactions between these systems and those of temperate latitudes. For example, how much water vapour, heat and momentum is transported upwards by tropical convective clouds and then polewards by these and other mechanisms; how are the synoptic-scale easterly waves in the trade winds modified by the motions within the associated, smaller-scale (100–1000 km) cloud clusters—and vice versa; how are the clusters themselves

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† GARP = Global Atmospheric Research Program.

affected by cumulonimbus groups or lines (of scale 10–100 km) which they frequently contain, and how is the development of a line modified by an individual large cumulonimbus (of scale 1–10 km) and its downdraught; and in what way is the cloud development dependent on the subkilometre-scale properties of the atmospheric boundary layer over the ocean, and vice versa?

By 1977 most of the agencies from the 10 countries which operated the aircraft and other equipment had by extraction of instrumental drifts improved the quality of the data collected to a state in which they were capable of being distributed to the world-wide scientific community to use in its investigation of problems just mentioned. It is therefore an opportune time not only to display the kind of information collected by an aircraft (in this case the United Kingdom's C-130, one of three superbly instrumented 'gust-probe' aircraft which took part in GATE) but also to demonstrate how successful the aircraft program was in supplementing and complementing the data from other sources.

The aircraft role in GATE

The phenomena of larger scale, i.e. the easterly waves and the cloud clusters, were investigated mainly by meteorological instrument packages on, or launched from, the ships. The most concentrated arrangement of ships was deployed in the eastern Atlantic and consisted of outer and inner hexagonal arrays, and—for the last three week period of the Experiment only—an inner triangle, as shown in Figure 1.

Eight long-range aircraft (flying from Dakar) were the most important instrument platforms for the investigation of the wind, temperature and humidity fields above the surface and the transports of momentum, heat, and moisture associated with the mesoscale convective systems (of scale <100 km) mentioned earlier. Three of these aircraft were equipped with 'gust probes', each carrying wind vanes and rapid response thermometers, which allowed measurements at a very high frequency (up to about 50 samples per second) to be made of the two horizontal and the vertical components of the wind velocity and of temperature, and a microwave refractometer from which similar measurements of humidity could be derived. This capability of high-frequency measurement also made these aircraft as important a tool as the tethered-balloon systems operating from the ships for investigating the microscale structure of air motions in the boundary layer, on scales down to 10–20 m.

Most flights were made in the area of the inner hexagonal array of ships shown in Figure 1, so that aircraft data would be combined with the large amount of data from upper-air soundings, weather radars, and tethered balloons operated from, or on, the ships. The specific objectives of a mission on any given day, and the flight plan necessary to achieve those objectives depended primarily on the structure and development of the clouds within the array on the day. 'Basic GATE missions', to investigate the dynamics of mesoscale cloud systems, were normally carried out by a stack of three to seven aircraft flying at different altitudes (typically from 500 to 37 000 ft) along the same ground track on any one of the patterns shown in Figures 2(a)–(c); these patterns were normally repeated by each aircraft, either in the same area or being moved with the group of clouds being studied. Such missions, including six flown outside the ship array to investigate the intertropical convergence zone (ITCZ), were flown on 29 days. On most other days emphasis was placed on determining the transports of momentum, etc., in the atmospheric boundary layer with a better vertical resolution than could be achieved from a basic GATE mission. One way of doing this was to concentrate the stack (but using at most four aircraft) into a layer from about 50 ft to 5000 ft above sea level (a.s.l.); more frequently a supplementary flight plan was used, as shown in Figure 2(d), in which 'L'-shaped patterns were flown by one or more aircraft frequently near a ship with a tethered balloon which also carried boundary-layer instrumentation. On

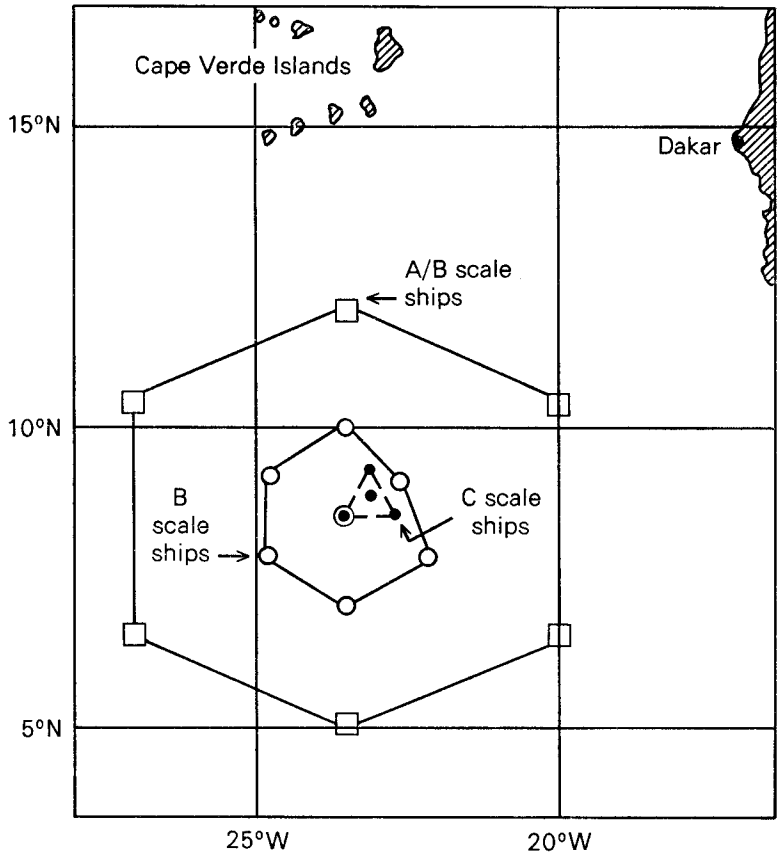

Figure 1. Location of ships in the eastern Atlantic for the third phase of GATE (30 August–19 September 1974). The A-scale is over 1000 km, B-scale 1000–100 km and C-scale 100–10 km.

these patterns the aircraft often made measurements at 4 to 11 levels between 50 and 5000 ft a.s.l. Boundary-layer missions were flown on 14 days.

The emphasis in this paper is on describing aircraft measurements made on basic GATE and boundary-layer missions and correlating aircraft data with data from ships' radars and balloon systems for each such mission. However, it should be mentioned that other missions were made by some of the eight long-range aircraft with other aims—for example measurement of the physical properties of clouds, of atmospheric (including cloud) radiation, and of sea-surface temperature fields (by a radiative method)—which were also essential to the main purposes of GATE. Additionally a further four aircraft were used in different roles—one examined wave profiles of the sea surface and performed detailed mapping of sea surface temperatures, two short-range aircraft performed a variety of special missions near Dakar, over both the ocean and the African Continent, and finally one aircraft was used to drop sondes over the east Atlantic thus supplementing ship data on large-scale phenomena. This last role exemplifies the wider usage to be made of research aircraft in future projects.

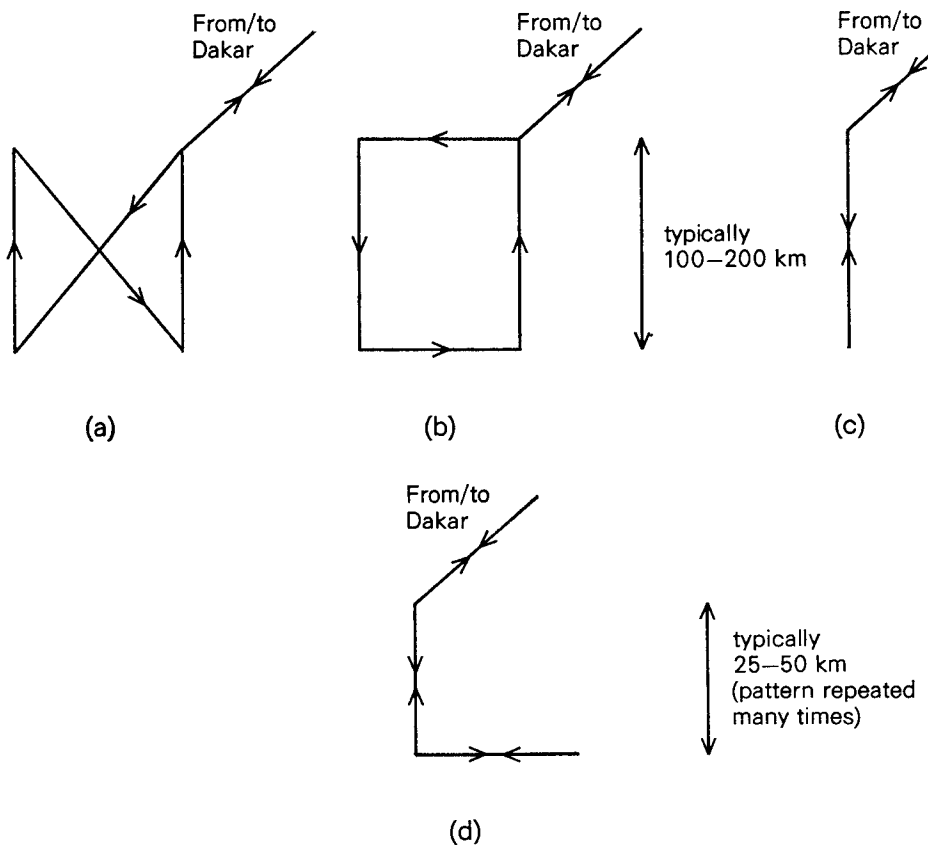

Figure 2. Basic GATE mission flight tracks: (a) butterfly pattern, (b) box pattern, and (c) line traverses; (d) shows the 'L'-pattern used for the boundary-layer missions only.

The United Kingdom's aircraft contribution

The United Kingdom's Hercules (or C-130) aircraft of the Meteorological Research Flight (MRF) was one of the three gust-probe aircraft used throughout GATE. This aircraft flew on 40 missions in all—27 basic GATE missions (including six crossings of the ITCZ), 8 boundary-layer missions, 1 sea-surface temperature mapping mission, and 4 flights solely to compare its measurements with those from other aircraft and an instrumented tower. Flying time totalled 386 hours, and about 10^9 samples of data were collected on the aircraft's magnetic-tape data-recording system.

Detailed information on the instrumentation of this aircraft may be found in the papers by James and Nicholls (1976) and Nicholls (1978). The importance of any errors in calculations derived from instrument measurements varies with the use which is to be made of the data. For example a calculation of convergence of air into a box will be most affected by the error of the mean wind component across one side of a box *relative* to that across the opposite side; the calculation of the vertical flux of heat on a leg of a boundary-layer flight will depend not on any absolute errors, but on any random noise and unreal drifts remaining in the computed vertical component of air velocity and on how the noise and drifts were correlated with those in the computed temperature. For this reason the accuracy of measurements made by the aircraft is a complicated issue and will not be discussed in great detail here. However, in general the absolute accuracy of any individual calculation of the horizontal wind vector,

temperature and humidity are about 2 m s^{-1}, 0·3 °C and 0·3 g (of water) per kg (of moist air) respectively, the contributions to these values from noise and drifts over short periods (over about five minutes) being about one-fifth of the value quoted. Detailed visual examination of continuous time series for parameters from which the vertical component of air velocity is calculated reduces the total error of any one sample to about 0·2 m s^{-1}, this contribution coming almost entirely from noise and short-period drifts of instrumental origin. Similar errors will apply to data from other aircraft.

In common with other research groups, the MRF has taken about 2½ years to complete the processing (mainly by computer) of the large volume of data, the removal of known instrumental drifts and errors, the derivation of meteorological data from the basic instrumental outputs, the 'validation' of data (see below), and the presentation of three data sets in an internationally agreed format on magnetic tape. The primary data set contained the three components of wind, and temperature and specific humidity at 20 samples per second (i.e. 20 Hz) of flight time, and the other two included one-second and one-minute mean values of these and all other recorded parameters. 'Validation' consisted of the checking by eye of plotted output of all the data to assess if the numerical procedures for 'cleaning up' the data had worked; in all about 20 000 plots of the 20 Hz output, together with a similar number showing 2 Hz output (for non-gust-probe parameters) were checked. Any remaining periods of poor data were listed in a set of documents completed for each flight, and the magnetic tapes and documents were then dispatched to the two World Data Centres (WDCs) in Washington and Moscow, and to five other data centres, scattered world wide, whose responsibility is to check the data from one platform against that from all others which were operating at the same time. It is not necessary, however, to await the results of this final verification in order to make a reasonable assessment of how well the aircraft data correlated with those from other sources. In the following description of two basic GATE missions and one boundary-layer mission a very good agreement is demonstrated.

Basic GATE mission of 5 September—cloud cluster

On this day six aircraft flew box patterns at levels from 500 to 39 000 ft within the dumb-bell-shaped cluster shown at midday near 10°N on the visible satellite photograph (Plate I). The U.K. C-130 flew two box patterns at the lowest level. The cluster was associated with a wave of synoptic scale propagating from the east in the trade wind flow. The internal structure of the cluster at 1252 GMT as shown on the radar picture from the Canadian ship *Quadra* (positioned at 9°1′N, 22°32′W) can be seen in Plate II, with the aircraft's flight track superimposed on the picture. The flight started at the north-east corner of the box at 1215 GMT, the first run being southbound, and ended at the same point at the end of the fourth (eastbound) run at 1405 GMT. Since significant changes in the structure of some of the cumulonimbus groups took place over the period of the flight, it is not reasonable to correlate aircraft observations with the features on this particular photograph; in order to examine the correlation between aircraft and radar data it is necessary to look at sequential radar photographs, throughout the flight period, of convective structure near to the aircraft's location as it flew along the four legs of the box.

The basic features of the radar echo are shown again in Figure 3, but in this case the features are reconstructed in segments from shots taken at quarter-hour intervals from the ship *Oceanographer* (at 7°45′N, 22°12′W). The *Oceanographer* radar had an isoecho-contouring facility, and in the figure only the second and third levels of intensity, corresponding to rainfall rates of greater than 1·5 and 6·1 mm h^{-1}, are shown. It can be seen that a very complex mesoscale rainfall system existed within the cluster boundaries with the most active convection near the southern edge of the cluster.

Figure 3 also shows a few of the aircraft measurements. On run 1 (southbound) generally light easterly winds were found. Large directional changes at the start of run 2 (westbound) were followed

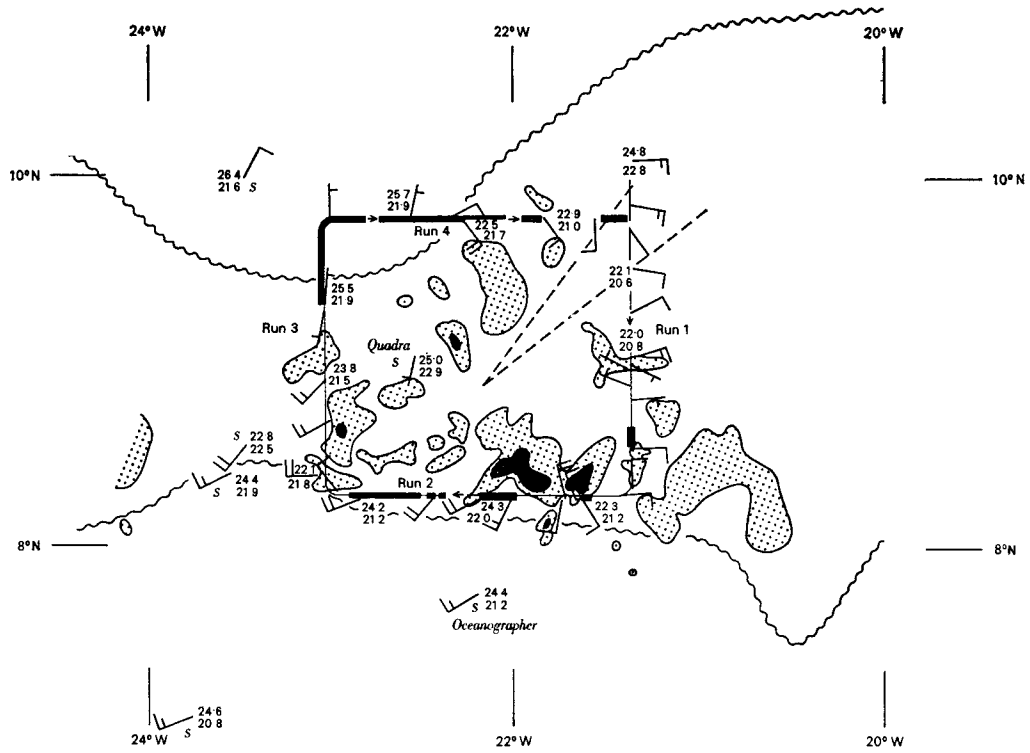

Figure 3. Montage of radar echoes from segments centred on aircraft positions at quarter-hour intervals, with apexes all at the centre of the box. Second and third levels of radar intensity are shown stippled and solid respectively. Aircraft flight track is shown by a thin solid line (in rain) or a thick solid line (in dry conditions). Winds, temperature (upper figure, degrees Celsius) and dew-points (lower figure, degrees Celsius) measured at points along the flight track are also shown. Ship measurements are annotated *S*. Cluster boundary as shown by satellite photograph denoted by a wavy line.

by a moderate south-westerly flow which persisted until a very abrupt change occurred to a light northerly flow near the end of run 3. At the same point a change also occurred from the cool humid disturbed air to warmer (by some 2 °C), calmer conditions (temperatures and dew-points are shown near some of the wind arrows). The region of northerly winds was found along the north-west quadrant of the box, with a further abrupt change in wind and temperature conditions (to humid south-easterlies) occurring halfway along run 4. If the track of the aircraft has been correctly derived relative to the radar and satellite features, we can see that the light easterlies, on run 1, with localized zones of slight convergence are associated with the limited convective activity on the eastern (trailing) edge of the cluster, and that the much larger convergence zones at the start of run 2, where rapid changes of wind from 10 kn southerlies to 20 kn northerlies were found, appear at the southern boundary of the most active convective elements. Also the south-westerlies at the southern edge of the box appear to be associated with air to the south of the active part of the cluster, with the change to the northerly regime occurring on and persisting after transition to the north of the cluster. As already stated, the structure of features of scale about 10–20 km—the cumulonimbus groups—changed significantly during the

2-hour period of flight around the box, but the general cloud distribution within the box did not. It thus seems reasonable that the wind field around the box changed only slowly during this period, and the aircraft measurements show an overall convergence of $4{\cdot}0 \times 10^{-8}$ s^{-1} into the 30 000 km^2 box. The correlation of aircraft wind and rainfall, and radar rainfall data, critically dependent on the accuracies of the derived aircraft and ship positions, is discussed in more detail later.

Observations of wind, temperature and dew-point measured at (or interpolated at) the 500 ft level by six ships in the B- and C-scale arrays close to the flight track are plotted on Figure 3. Splendid agreement can be seen between the aircraft and ship data within, to the south and to the north of the cluster (although the ship data presented here were not taken from a set of finally validated data).

Figure 4 shows wind, vertical air velocity and rainfall data from the aircraft as a function of time for each run individually, together with levels of radar intensity from *Oceanographer* photographs taken at 5-minute intervals. The scale of time is reversed for run 2 to preserve the west end of the run on the left of the figure, and similarly the north end of run 3 is so preserved; one minute of flight time corresponds to about 6 km flown. Wind vectors at 2-minute intervals are supplemented in active convergence zones by further vectors. The vertical component of air velocity shown is the maximum updraught in any 10-second period where the mean exceeded 0·5 m s^{-1}. The rainfall observations from the aircraft are derived from direct observations by the on-board scientist and from refractometer indications of the presence of rain; rainfall intensities are given when qualitative estimates were made by the observer. It can be seen that there is a good correlation of these rainfall observations to the radar intensity levels, with zones of no observed rainfall corresponding well with zero radar return and heavy precipitation falling where the most intense radar echo was found, even though the radar was 'seeing' the convective elements at levels above the flight level (some 10 000 ft above for the northern part of the box). Even the transition from continuous rain to showers noted by the observer on run 2 (at 1300 GMT) corresponded to a transition from continuous echo to an area of individual convective elements on the ship's radar photographs. Minor differences in the location of rain observed from the aircraft and radar echo could be due to the discrepancy in levels of observation, or to an error of aircraft location relative to the ship radar of about 2 km which for a mid-oceanic rendezvous indicates a good performance of aircraft navigational equipment and of procedures for correcting the output of that equipment. The correlation, using radar photographs taken at intervals of a few minutes, indicates that even in a complex mesoscale convective system embedded in a cluster the aircraft positions were known with sufficient accuracy to relate on-board dynamic and physical measurements to radar echoes and their development.

The vertical velocity fields measured by the aircraft's gust probe are shown by the vertical bars. The largest updraughts and downdraughts were measured at the edge of the major convective system at the start of run 2 in the transition zone from easterlies to south-westerlies, with an updraught of nearly 4 m s^{-1} at the position of most enhanced convergence and a mean updraught of 2 m s^{-1} over about 1·5 km centred at this point. Several sustained updraughts of 0·5 m s^{-1} (persisting 0·5 to 3·0 km) were found in the south-westerly regime in the south-west of the area, indicating that the development of localized convergence followed by showers within that airstream (rather than any large-scale convergence) was the main cause of any precipitation encountered there, and possibly that at the 500 ft level (on run 3 only) the aircraft was flying parallel to but marginally away from the major convergence zone whilst experiencing the rain produced by it.

The answer to suppositions such as these would probably follow from an analysis of data (including photographic data) from *all* the aircraft. It has, however, been demonstrated here that aircraft and radar data can be very effectively correlated even in a very complex situation. The next case illustrates how well data from several aircraft, as well as from radar, fit together when the mesoscale dynamics of a cloud line in the intertropical convergence zone are examined.

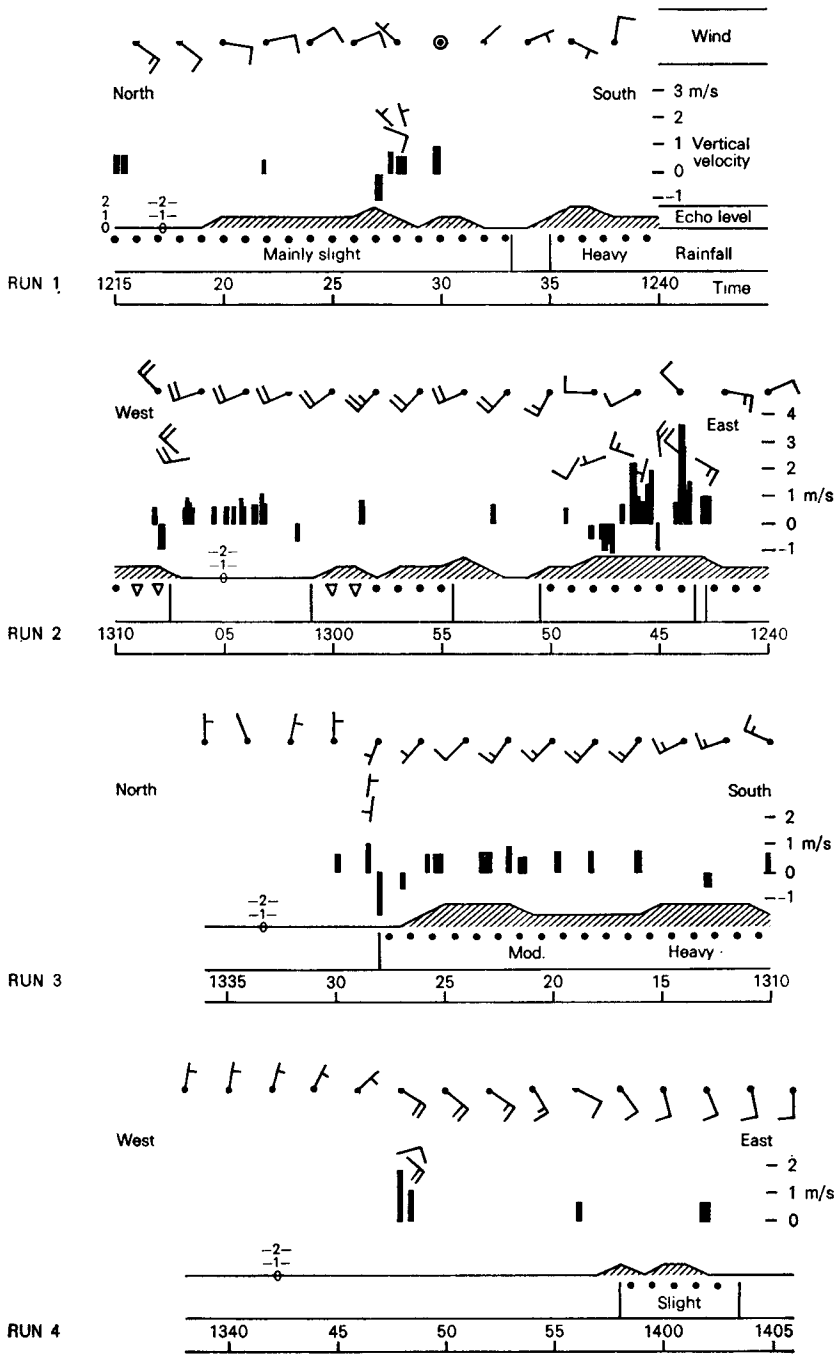

Figure 4. Aircraft wind, vertical air velocity and rainfall measurements as a function of time. Winds (usual notation) are shown at 2 min intervals, supplemented by further measurements in active convergence zones. Vertical bars show maximum updraught velocities in any 10 s period when the mean exceeded $\pm 0{\cdot}5$ m s^{-1}. Rainfall is shown as a dot (continuous) or a triangle (showers) and intensities are indicated when known. Radar-echo intensities from the *Oceanographer* are derived from photographs, taken at 5 min intervals, of cloud structure near the aircraft.

Basic GATE mission of 3 August—cloud line

A brief discussion of data obtained from two American aircraft on this day has already been presented by LeMone (1975) and some of these are used here. On this day the three gust-probe aircraft (the Electra at 600 ft, the U.K. C-130 at 1300 ft and the DC 6 at 5000 ft) each flew several traverses along straight lines through a group of cumulonimbus clouds on the northern edge of a marked intertropical convergence zone; the zone is shown in the satellite photograph (Plate III). An aircraft without a gust probe flew at 10 000 ft but data were not available from this aircraft at the time of writing. The structure of that part of the zone investigated by the aircraft is shown by the 1324 GMT radar picture (Plate IV) taken from the ship *Oceanographer* (at 8°31'N, 23°28'W). The group consisted of an almost east–west line of clouds some 130 km south of the ship and successive radar photographs show that the line maintained its identity and intensity through most of the flight period, although other lines (probably of 'feeder' cumulus clouds) were sometimes present to the south of the primary line. Figure 5 shows details of the 1324 GMT photograph with the aircraft track (which remained fixed with time), winds and temperatures (for the run from 1322 GMT to 1338 GMT) superimposed. It can be seen from the wind field that it is the variation in northerly component which is the chief cause of convergence within the cloud.

Figures 6 and 7 respectively show the vertical and southerly wind components averaged over about 5 seconds, measured by the U.K. C-130 gust probe for 5 traverses of the line over a 2-hour period. At the flight level the convection is associated with a convergence (marked S on Figure 7) of up to 6 m s^{-1} over about 7 km, the zone of convergence moving steadily south at 3 m s^{-1} throughout the period. As seen from Figure 6 the convergence zone produced up- and down-draughts of up to 4 m s^{-1} at 500 ft; the associated cloud (as noted by the on-board observer and from the aircraft radar) was also found to be moving south at 3 m s^{-1}. Figure 8 shows fluctuations of water vapour content (or specific humidity), temperature and the vertical component of air motion on the penultimate run (run 4). There was very little difference between conditions on different sides of the convergence zone, the air to the north being very slightly warmer and drier than that to the south. The intensity of the radar echo is also shown and correlates perfectly with the zones of principal updraught both near 6·9°N and between 7° and 7·1°N. The correlation with the observed rainfall is not as good because the radar was 'seeing' the precipitation at 15 000 ft, well above the aircraft and 'feeder' cumulus clouds which were producing the rain experienced at the southern end of the run.

The southerly wind component measured by all three aircraft flying in a stack on run 4 is shown in Figure 9; the location of the convergence zone is almost identical at all levels and even a consistency in some of the mesoscale structure is identifiable from level to level; for example a minimum in the southerly component can be seen at point A in the centre of the shear zone. Since the cloud was moving southwards at 3 m s^{-1}, the aircraft measurements indicate that at the 500 ft level air was entering the cloud almost entirely from the south (at about 7 m s^{-1}), at the 1300 ft level it was entering primarily from the south at about 5 m s^{-1}, and at the 5000 ft level it was entering almost entirely from the north at about 2 m s^{-1}. The air motions relative to the cloud with a few spot-temperature measurements are shown in the schematic representation of a north–south cross-section of the cloud in Figure 10. Radar-intensity levels measured above the flight tracks from the *Oceanographer* are also shown, and there is perfect agreement between the location of the convergence zone and that of the maximum radar intensity.

This case illustrates primarily a marked consistency between mesoscale measurements from the three gust-probe aircraft as well as a good correlation again with ships' radar data.

We will next look at data from a boundary-layer mission to demonstrate a consistency between measurements of microscale features as measured by aircraft and some tethered-balloon data.

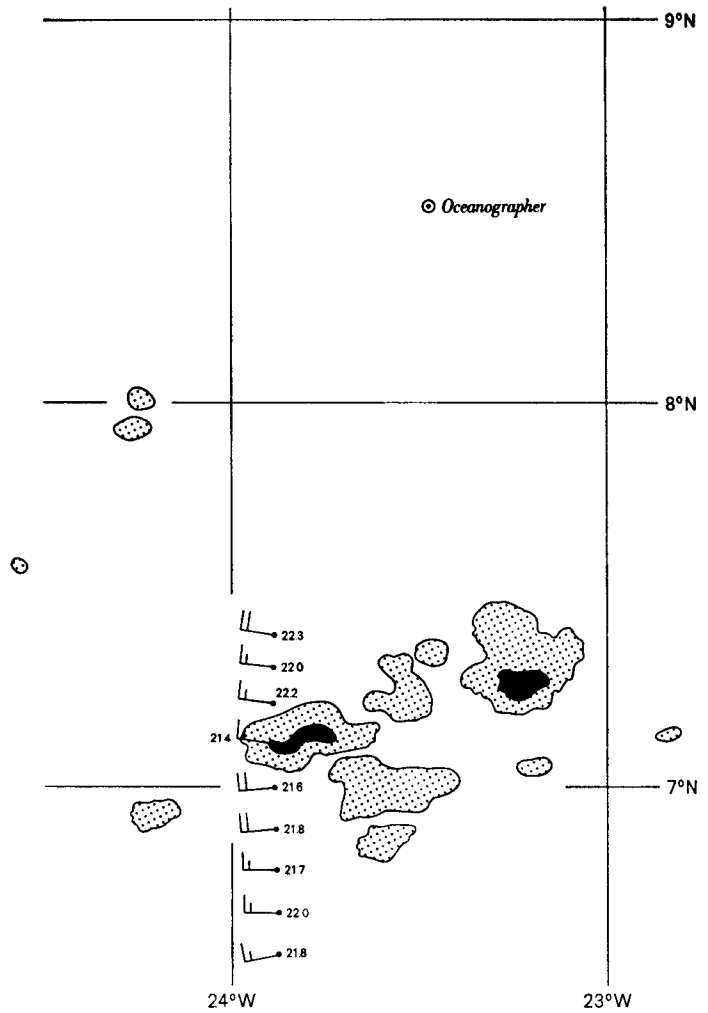

Figure 5. Details from the 1324 GMT radar photograph, annotation as for Figure 3. The flight track for the run from 1322 to 1338 GMT is shown, with wind and temperature measurements at 2 min intervals. The wind direction is shown in tens of degrees.

Boundary-layer mission of 7 September—suppressed convective conditions

The U.K. C-130 and American DC 6 flew 'L'-shaped patterns at several levels between 50 ft and 2500 ft a.s.l., close to the ship H.M.S. *Hecla*, which was operating a tethered balloon with attached turbulence sensors. The legs of the L patterns were about 45 km (25 n. mile) long. Convection was generally suppressed, with small randomly distributed cumulus clouds (base at 1400 ft) which at the start and the end of the flight were just producing rain.

Data presented here are from the six runs along-wind (over the same track) flown by the C-130 at 100, 300, 700, 1250, 1900 and 2500 ft a.s.l. The first and second runs passed through localized precipitation, and run 6 traversed a few small cumulus clouds. During runs 3, 4, and 5 little cloud was present at all, generally 1 okta of small cumulus. Figure 11 shows representative 2 Hz vertical velocity data from one-

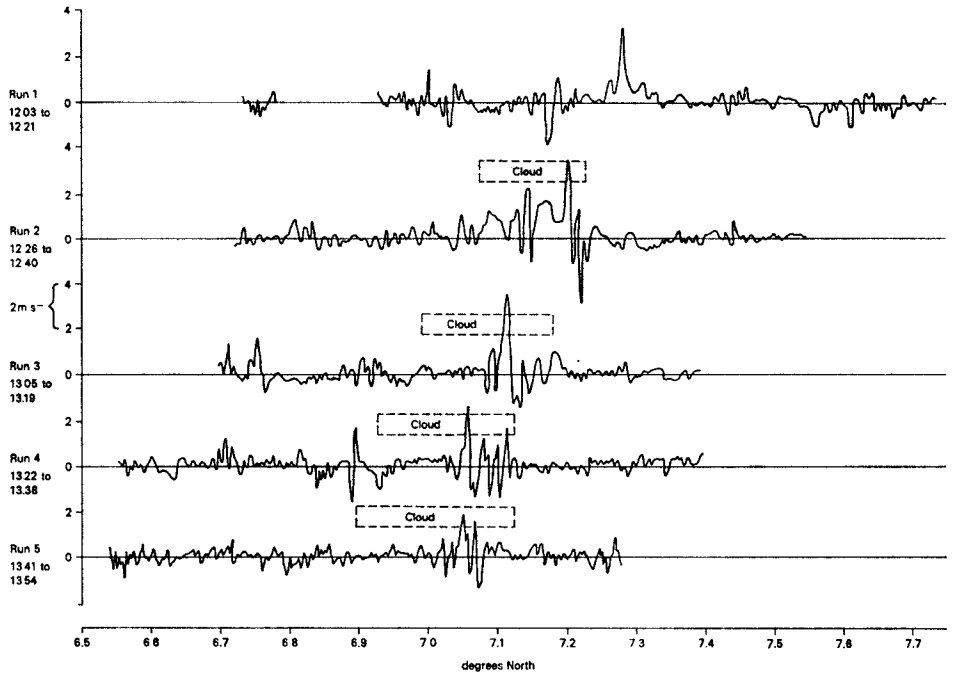

Figure 6. Vertical wind component measured on the aircraft on five sequential traverses of the cloud line on 3 August, as a function of latitude. The location of the principal cloud line on the last four runs is also shown.

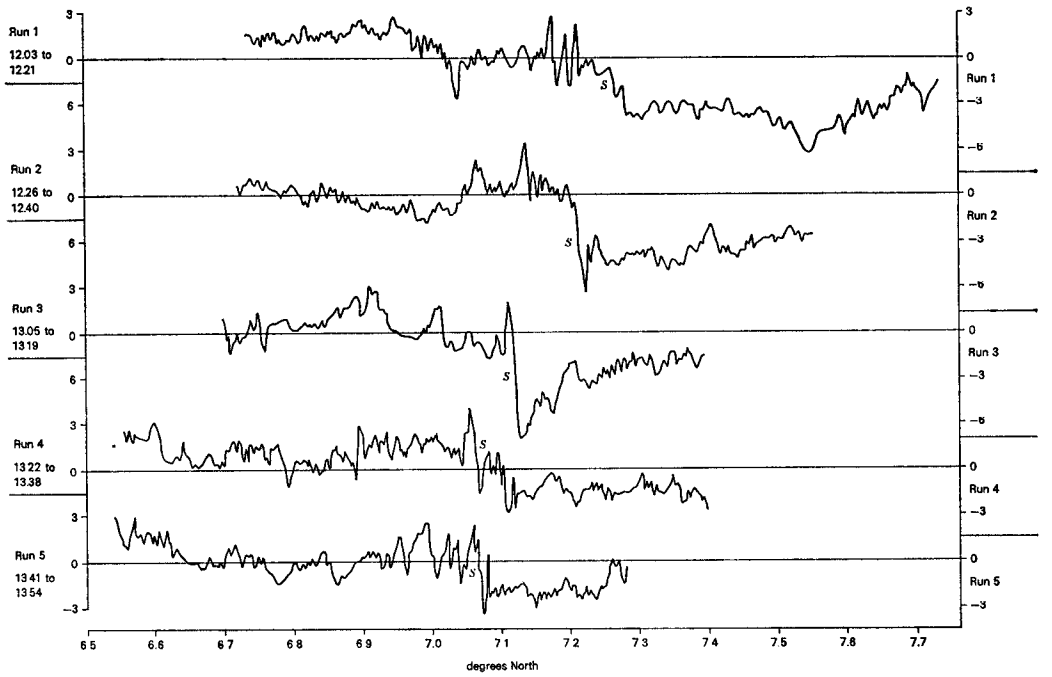

Figure 7. Southerly wind component measured on 3 August as a function of latitude. The major shear zone is annotated 'S'.

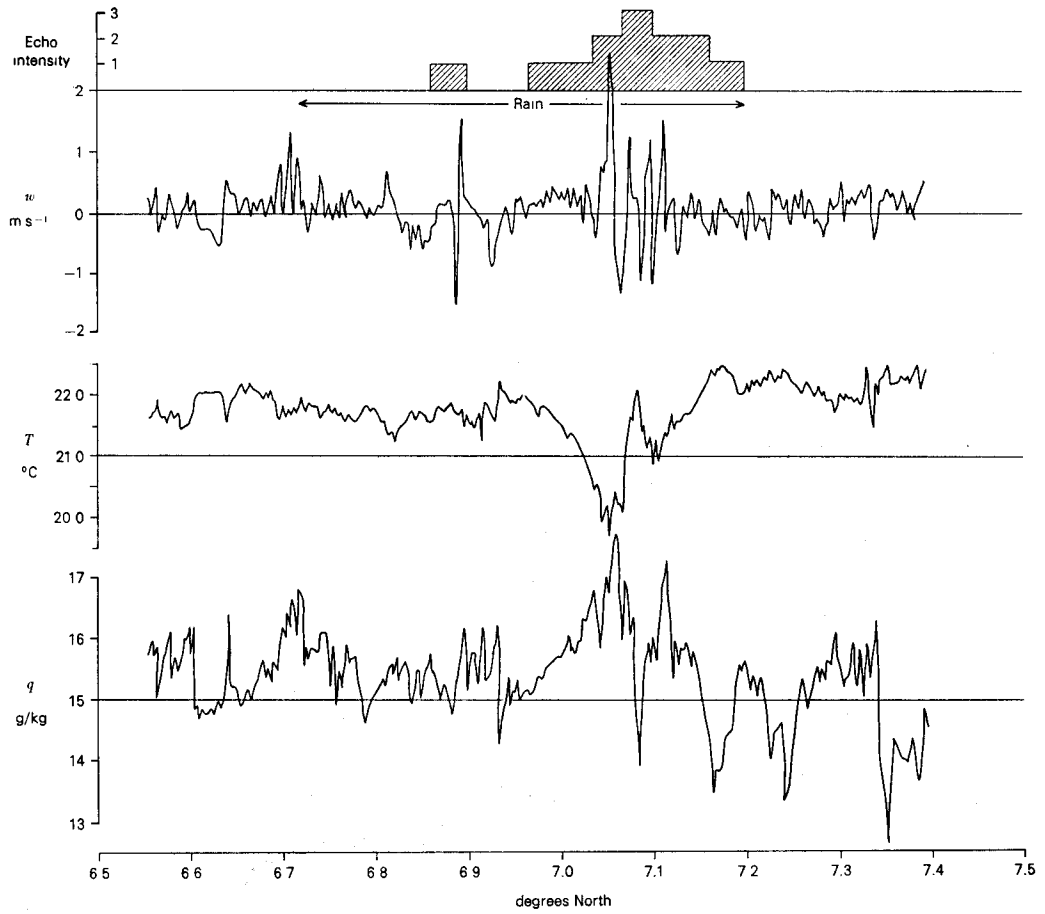

Figure 8. Profiles (as a function of latitude) of the vertical component of air motion, temperature and specific humidity measured on the penultimate run (1322–1338 GMT) by the aircraft. The radar intensity is also shown, as derived from the 1324 GMT data from the *Oceanographer*.

minute sections of each run. It can be seen that above the 300 ft level the amplitude of the high-frequency content decreases, and (except in cloud) by run 6 only longer-period oscillations (of about 1 km wavelength) were evident. Although convective conditions appeared to be highly suppressed during the middle of the flight, significant mesoscale perturbations in temperature and water vapour content were still in evidence as are shown by the data from run 3, (Figure 12), and are perhaps indicative that the properties of the air at sub-cloud levels had been modified by precipitation which had fallen earlier.

The vertical fluxes of momentum $\rho\overline{u'w'}$, heat $\rho C_p\overline{w'T'}$ and latent heat $\rho L\overline{w'q'}$ are shown in Figure 13 as a function of height; u', w', T' and q' are respectively the perturbations in horizontal wind, vertical wind component, temperature and specific humidity. The sensible-heat flux is rather randomly scattered but in any case is an order of magnitude less than the latent-heat flux, which reaches 140 W m^{-2} at the 300 ft level. The latent-heat flux then drops markedly but is still positive at the 2500 ft level, some 1000 ft above cloud base. The component of momentum flux along the wind also decreases rapidly with height, from 0·9 N m^{-2} at 300 ft to zero at 2500 ft. Unfortunately data from the DC 6 are not available,

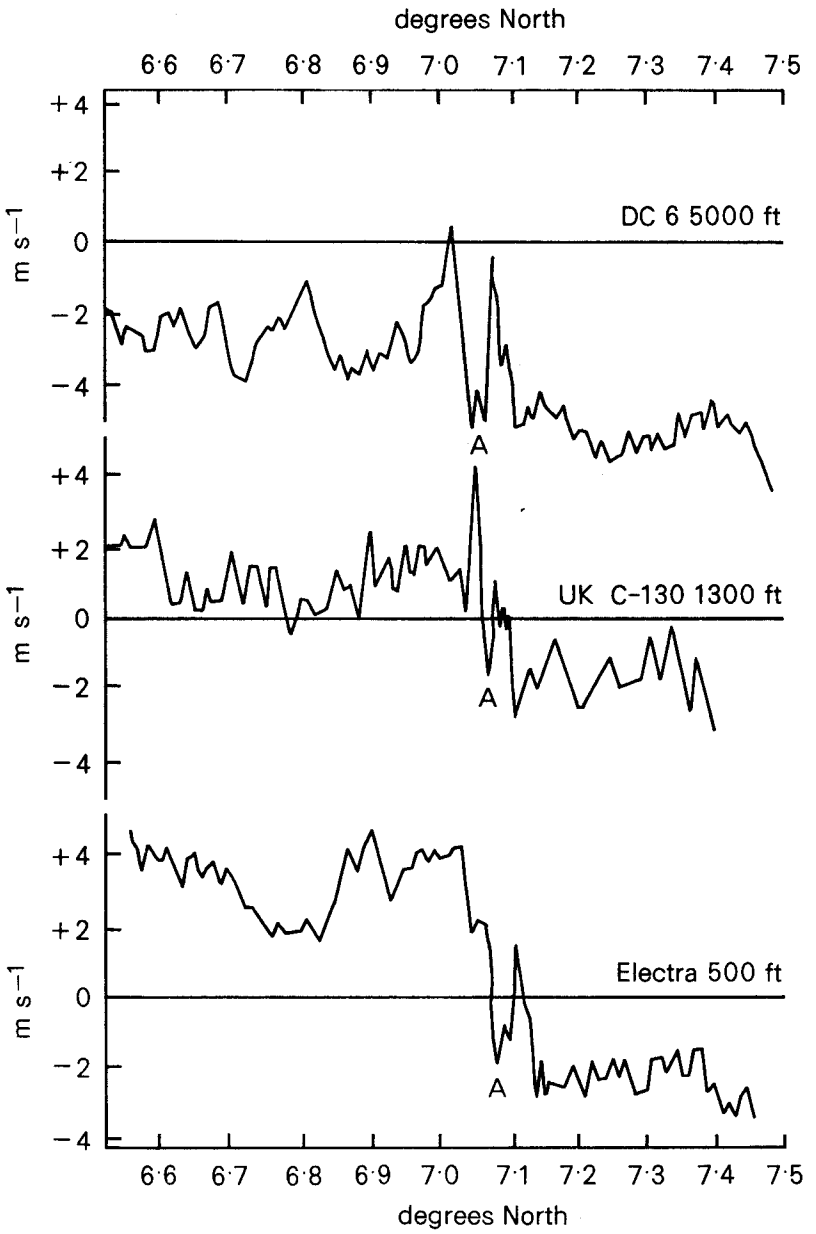

Figure 9. Southerly wind component measured by three aircraft flying in a 'stack' between about 1322 and 1338 GMT. For an explanation of point 'A' see text.

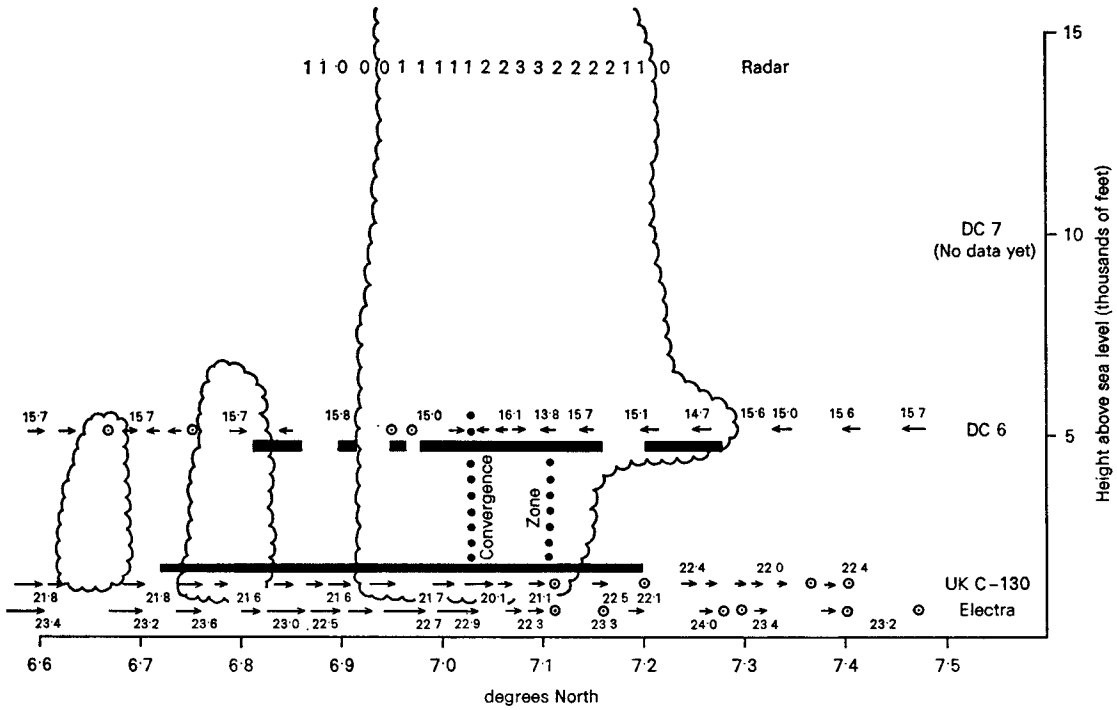

Figure 10. Schematic representation of a north–south cross-section through the cloud from the 1322–1338 GMT data on 3 August. Arrows represent the southerly component of the air motion relative to the cloud, with 1½ mm representing 1 m s^{-1}, as measured by the three aircraft. A circle with a dot in it represents calm. Temperatures are also shown at a few locations. Solid bars represent observed rainfall (from DC 6 and C-130 only). The radar intensity is shown at the level of intersection of the radar beam with the rain.

but data gathered by the American Electra aircraft on GATE in similar conditions (with small cumulus based at 1500 ft and a surface wind of about 7 m s^{-1}) presented by Grossman (1975) give profiles which are almost exactly the same as those for the C-130, and these profiles are also shown in Figure 13. A detailed meteorological description of the microscale and mesoscale phenomena giving rise to similar profiles near and below cloud-base level can be found in a paper by Pennell and LeMone (1974). Latent-heat fluxes computed at three heights from the tethered-balloon measurements on H.M.S. *Hecla* on 7 September are indicated on the same figure by crosses for observations as near as possible in time to the aircraft measurements. Again there is good agreement between the two sets of data although the comparison is obviously limited.

Conclusions

In each of the case studies illustrated above much more data were available than has been described, and of course the analysis of the data could have been carried much further. However, it has not been the object of this paper to present in detail an analysis of convective and boundary-layer dynamics, but rather to illustrate the success of the aircraft role in GATE, the type of data gathered by the aircraft and in general how well this complements and supplements data from all other sources. It has also been shown how well data from different aircraft fit together, although this point is better established by

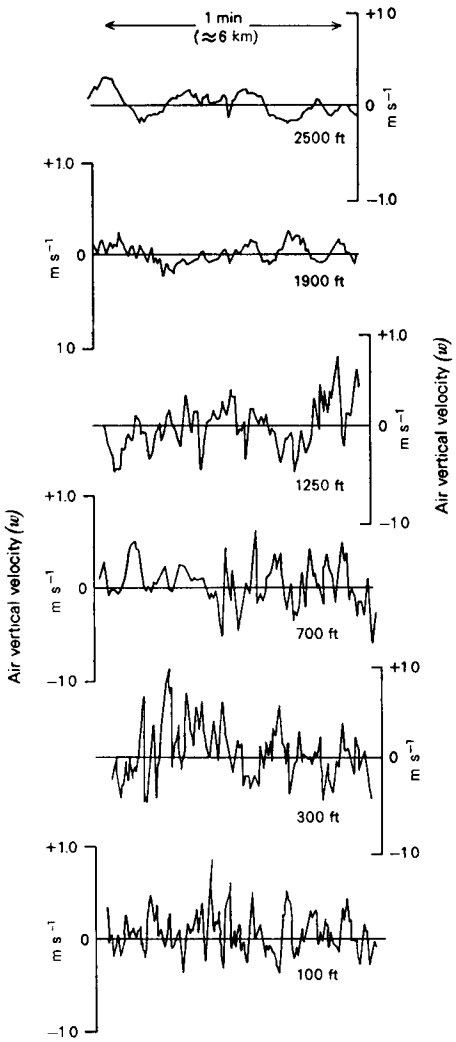

Figure 11. Representative 2 Hz vertical velocity data from along-wind runs of the U.K. C-130 on 7 September 1974. Flight levels (from the bottom of the diagram upwards) were 100, 300, 700, 1250, 1900 and 2500 ft.

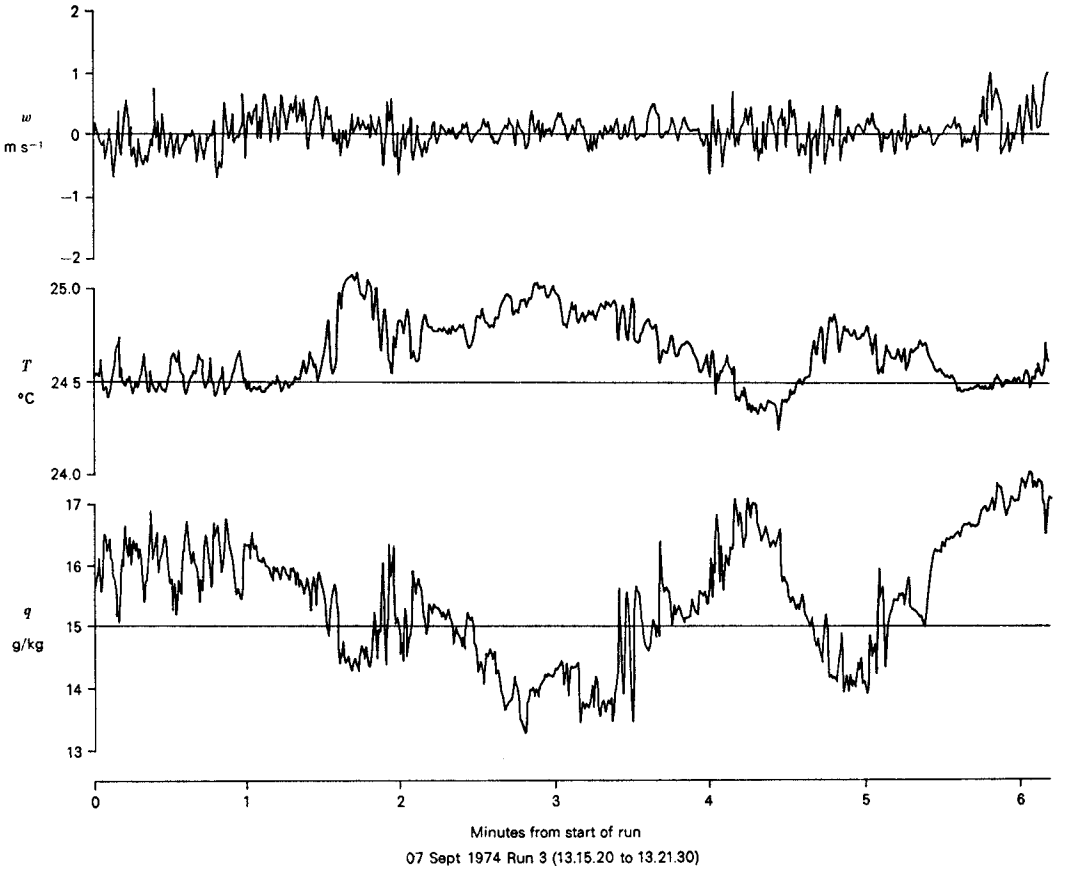

Figure 12. Profiles (as a function of time) of vertical air motion, temperature, and specific humidity from the along-wind run at 700 ft on 7 September.

examination of intercomparison data. Finally it should be emphasized that the data collected by aircraft and ships throughout GATE consist of samples collected in a variety of synoptic situations, ranging from very disturbed weather to samples in completely undisturbed boundary layers. It is the largest, cleanest volume of field data available to those working in many sub-disciplines of meteorology —boundary-layer fluxes, cloud dynamics, cloud physics, radiation, etc. The success of the project will finally rest on the use made of these data.

Acknowledgements

The author would like to acknowledge the work of and dedicate this paper to all those Meteorological Research Flight staff and Royal Air Force aircrew who participated in GATE, but especially to the data-processing team of R. Crawford, R. Ellis, D. Levy, P. Joy, S. Sherrington, R. Thackray and S. Wass who were responsible for two years of sustained effort to produce an outstanding data set available for international use. Thanks are also due to S. Nicholls for processing the boundary-layer data.

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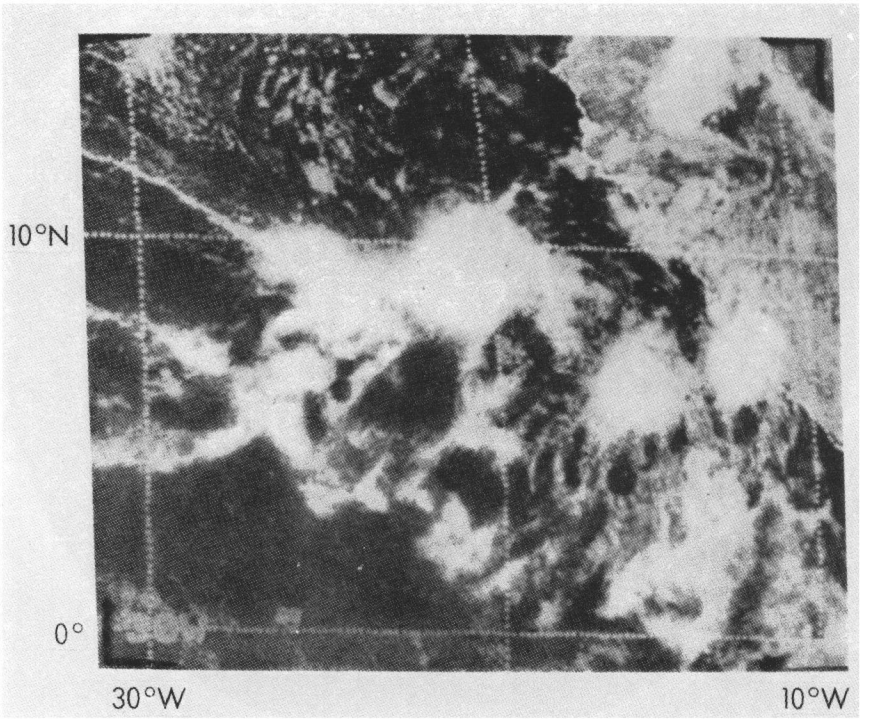

Plate I. Dumb-bell shaped cluster near 10°N at 1200 GMT on 5 September 1974 as seen from a geostationary satellite (radiation in the visible spectrum).

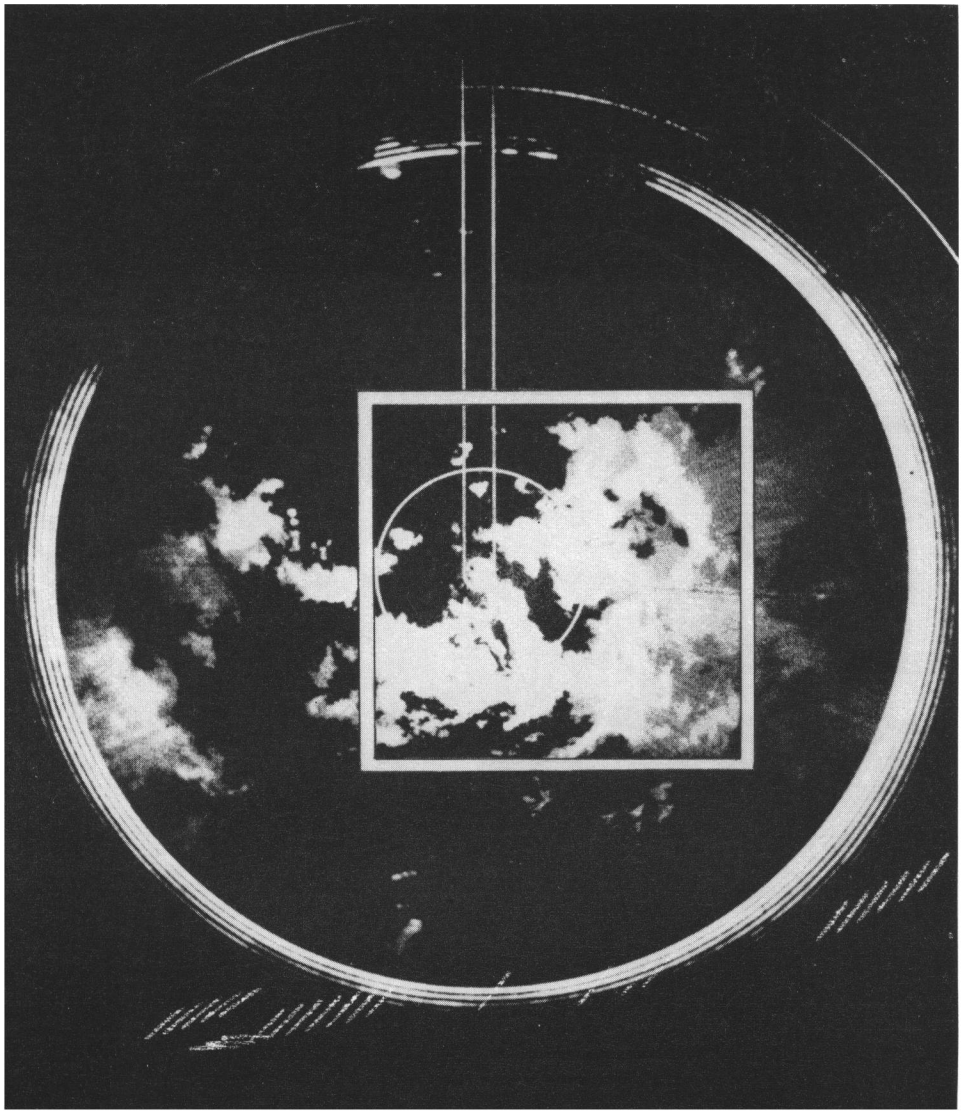

Plate II. Internal structure of cluster as seen on ship *Quadra's* radar at 1252 GMT on 5 September 1974. The ship is at the centre of the picture and true north is indicated by the two parallel vertical lines. The inner range marker (white circle) indicates a radius of 25 n. mile, and the radar range is just over 100 n. mile. In general the 'whitest' echo shows the heaviest precipitation. The aircraft flight track between 1215 and 1405 GMT is also shown by the box.

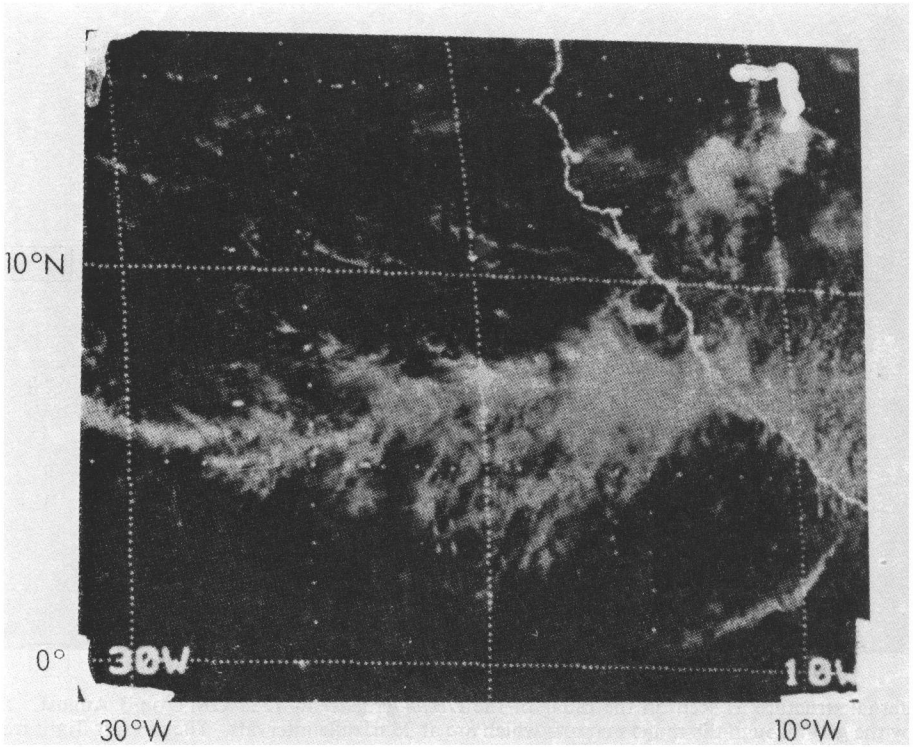

Plate III. Intertropical convergence zone cloud at 1200 GMT on 3 August 1974 as seen from geostationary satellite (visible spectrum).

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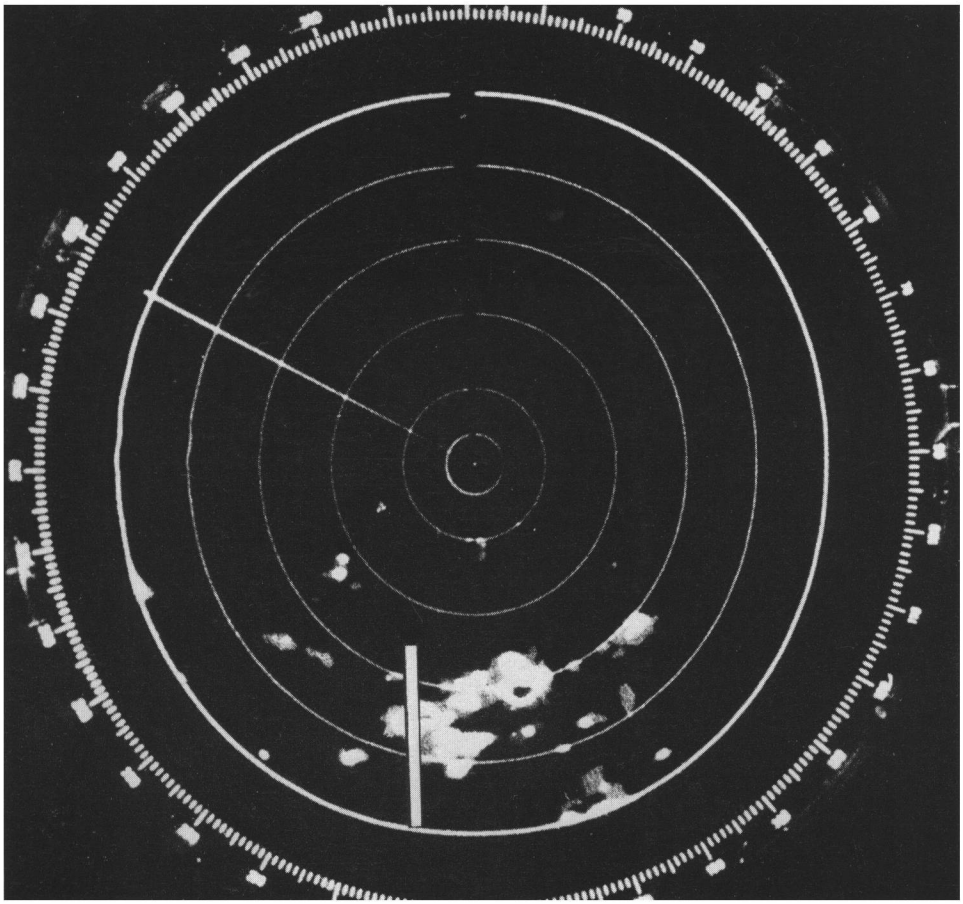

Plate IV. Internal structure as seen on the radar of the *Oceanographer* at 1324 GMT on 3 August. True north is indicated by the gap through the range markers which are at 25 n. mile intervals. The aircraft flight track, repeated between 1203 and 1354 GMT, is also shown.

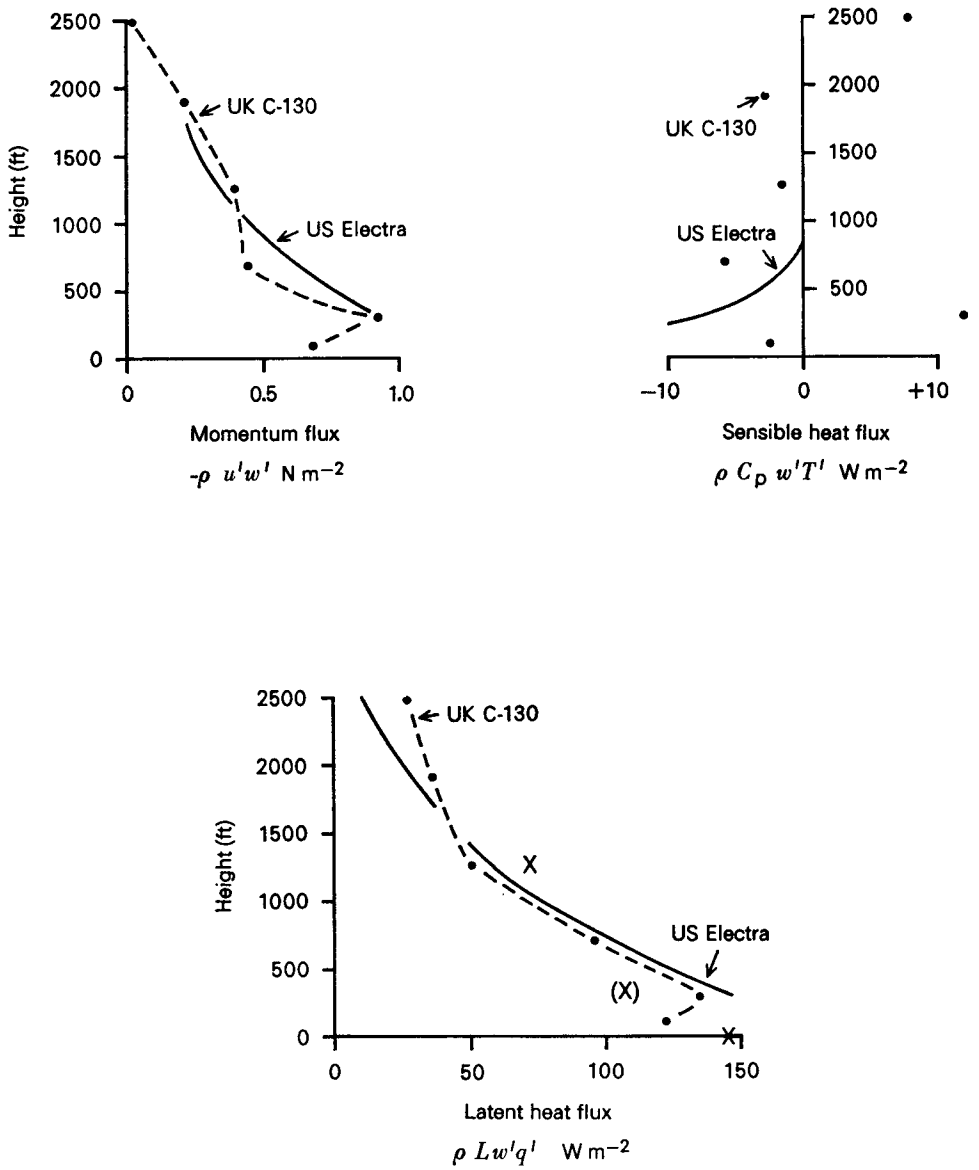

Figure 13. Profiles (as a function of height) of momentum, sensible-heat and latent-heat fluxes as measured by the U.K. C-130 on 7 September, and (from Grossman 1975) the U.S. Electra in identical conditions during GATE. Tethered-balloon measurements from H.M.S. *Hecla* on 7 September are shown by crosses. The bracketed value was obtained shortly after the flight.

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Diurnal variations of temperature and wind in the 25–65 kilometre region of the equatorial stratosphere

By G. C. Bridge

(Meteorological Office, Bracknell*)

Summary

A WMO sponsored comparison of meteorological sounding rocket sensors held in French Guiana in 1973 produced a set of stratospheric temperature and wind data up to a height of 60 km recorded near local midday and midnight. Measurement of the diurnal variation of these parameters was thus possible. Sinusoidal variation of temperature and zonal wind with height in the stratosphere was most noticeable from night to day, with an almost equal and opposite variation occurring from day to following night. Vertical wavelength of the main oscillation was around 11 km, with amplitudes of around 14 °C peak to peak for temperature and 16 m s^{-1} peak to peak for zonal wind. Diurnal variation of meridional wind component was more confused, with a combination of oscillations with smaller amplitude and vertical wavelength. The similarity to some rocket observations recorded from the island of Gan, in the Indian Ocean, was noted.

During the latter part of September and early October 1973 the Meteorological Office participated in the World Meteorological Organization sponsored Comparison of Meteorological Rocket Sensors, held at the Centre Spatiale Guyanais (CSG), Kourou, French Guiana in South America. The object of the comparison, organized by the Commission for Instruments and Methods of Observation (CIMO) was to resolve inconsistencies noted in meteorological observations to 60 km or higher being made by a number of countries. In essence it involved near-simultaneous firings of the different rocket systems employed by member countries, namely the American 'Super Loki Dart', the Russian M100, the British 'Skua' and the French 'Super Arcas' (of American origin), both in day-time and night-time conditions. This campaign was the second phase of a two-part comparison, the first held at Wallops Island, U.S.A. (Figure 1), during March 1972 in which France, Japan and the United States of America took part, and with Brazil and India observing.

In practice the total time required to fire all four types of rocket sequentially was approximately one hour, therefore it was assumed that changes occurring in the stratosphere over this length of time were considered negligible in order that a valid comparison of data could be made. As a check on the validity of this assumption, an extra Loki Dart was fired on five occasions, after the sequence of four, and its results compared with the first Loki Dart of the sequence. Since analysis of comparison data was performed by Leviton (1975) it is not the purpose of this paper to discuss the data in a comparative manner. However, the wealth of soundings made in a period close to local midnight and near local midday presented an excellent opportunity to investigate diurnal changes of both temperature and wind (in the form of zonal and meridional components) in the equatorial stratosphere (Table I). Data from the Russian M100 were not used in this analysis since large systematic errors were known to exist at that time.

The four types of rocket fired during the comparison were those most commonly used by the meteorological sounding-rocket agencies of the countries already mentioned. Each system carried its payload to apogee (with the exception of the M100, which liberated its payload and retardation device on the up-leg at around 50 km) between 70 and 80 km. At apogee the temperature sensor (either a fine wire filament, or a thermistor bead in the Loki Dart) and data transmitter were deployed, then descended,

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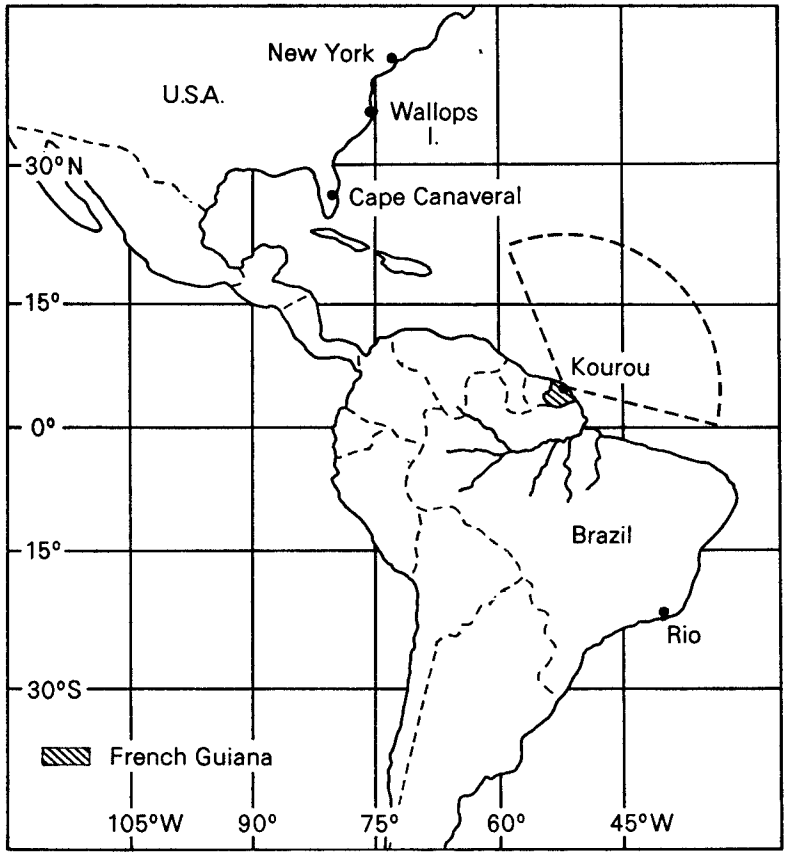


Figure 1. The position of the Centre Spatiale Guyanais, French Guiana, showing approximate range boundaries.

Table I. *Daily sequences of rocket firings.* (*All times local, i.e. GMT minus 3 hours.*)

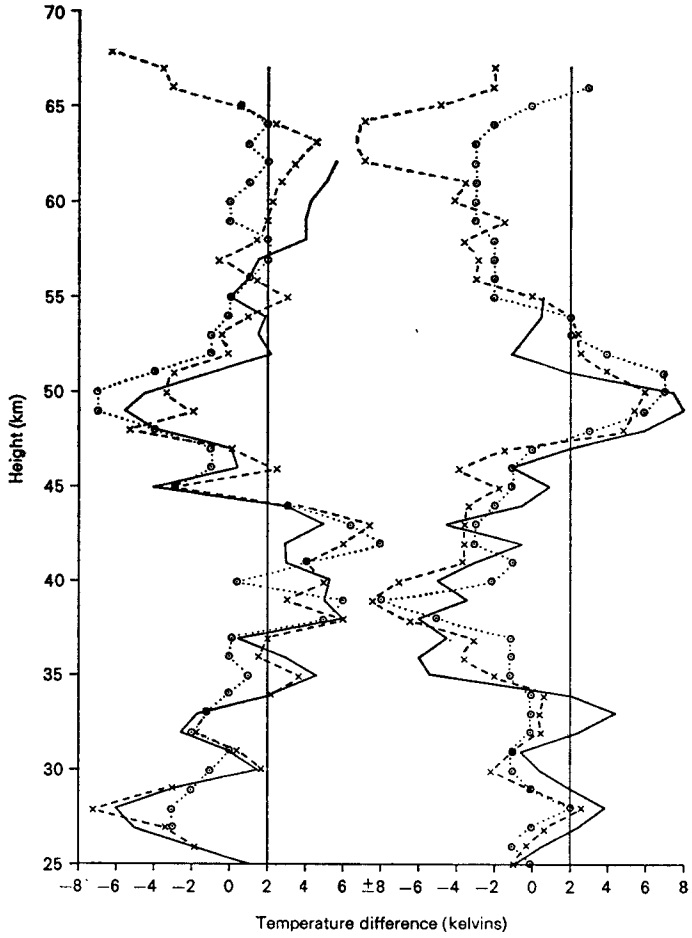
Date	Loki Dart		M100		Skua		Super Arcas		Loki Dart	
20 Sept.	1049		1142				1054			
21	0028	1213	0120	1223	0044	1239	0032			
22	0102		0112		0131		0137			
23										
24	1410	2119	1421	2129		2151	1415	2156		
25	1500	2110	1510	2122	1535	2201	1540	2206		2239
26	1104		1113		1135		1143		1214	
27	1037	2333	1106	2343	1120		1126		1158	
28		2352			0006		0011		0042	
29			0001		0024		0029			
30										
1 Oct.	0030		0040		0102		0108			

supported under some suitable retardation device, usually a silk parachute. The American system employed a Starute, a ram-inflated device rather similar in appearance to a high-level ballooon but with a collar or 'burble fence' around its horizonal diameter to increase drag. Coating these retardation devices with some radar-reflecting material enabled them to be tracked from the ground during descent, thus permitting the calculation of winds at various levels in the stratosphere. Temperature information was received at the ground via the various telemetry systems and suitably corrected. By far the most important corrections were those for dynamic heating (very large fall-speeds often well in excess of 150 m s^{-1} occur during the initial stages of descent) and for solar radiation (largest at apogee, falling off rapidly during the descent). Further corrections were applied to compensate for the imbalance of infra-red radiation between earth, space and the sensor, net albedo of the earth and cloud distribution below the sensor (daylight soundings), heat transfer between the sensor and its supporting structure and corrections for thermal lag in the sensor itself. For details of these corrections as applied to the Skua system, see Almond (1965) and Mason and Acres (1972). Wind information above 60 km was discarded for the comparison and also for this analysis since it was generally agreed that, above this level, momentum imparted to the descending payload by the rocket at separation was still present and would produce large errors in the computed wind components. Comparisons of night and day temperatures and wind profiles were always made with data from the same rocket system to eliminate errors arising from the different measuring characteristics of each payload. Values of temperature or wind component incorporating data from all systems are identified in the diagrams where appropriate.

An assessment of the mean temperature and wind variation from night to day (i.e. day observation minus previous night's observation) for each rocket system was made. There were three cases for Loki Dart, two for Skua and two for Super Arcas. A similar assessment was performed for the day-to-night variation (night observation minus previous day's observation) and the cases available for consideration this time were 5, 2 and 4 respectively. This is a small sample, but if similar variations were seen to occur using three independent measuring systems then confidence in the validity of the results would be greatly enhanced. The mean of all diurnal variations for each system is shown in Figure 2, together with average time difference between pairs of observations.

Immediately apparent from Figure 2 is the sinusoidal variation of temperature with height during the night–day comparison indicating warming near 62 and 40 km and cooling near 49 and 27 km. During the day-to-night change the exact opposite is seen to occur at almost identical levels although slightly larger amplitudes are apparent, a function of different time interval between observations. Time periods of the night-to-day sequences are about five hours longer than those for day to night, and the amplitudes of the main oscillation about 2 degrees smaller. Therefore an oscillation with a half period closer to 10 hours than to 15 hours can be inferred from these observations.

Due account must be taken of the effect of solar radiation on the sensors in biasing day-time temperature values during any night–day comparison. A typical correction with height, as employed on the Skua system, is shown in Figure 3. It can be seen that the largest correction occurs at apogee then decreases rapidly to small values below 40 km. The addition of a further 20 per cent (a typical correction for Kourou) was to take account of the reflection of solar radiation from the earth's surface. This albedo was computed giving due consideration to the type of surface in a circle of 500 km radius below and centred on the sensor, and the quantity and type, hence the reflectivity, of any clouds in this area. All four countries adopted various values for albedo, as used in their normal correction procedures. This accounts for systematic differences prominent above 60 km between pairs of observations. The oscillatory characteristic of the temperature profile is maintained however, despite these differences, with nodes at nearly equal height levels. This infers that variation in corrections for solar radiation below 60 km is not significant and the resulting diurnal oscillation is real. Small-scale differences



		Night to day (day minus previous night)		Day to night (night minus previous day)	
Key system		Ascents	Period (Hours)	Ascents	Period (Hours)
———	LOKI	3	14·1	5	10·7
×---×	SKUA	2	15·7	2	9·6
•·····•	ARCAS	2	15·7	4	10·1

Figure 2. Diurnal variations of temperature with height recorded by three different rocket systems during the CIMO comparison 1973.

between profiles demonstrate the rapid changes of temperature with time at certain levels. These are produced by a mixture of gravity waves of shorter unknown periods of oscillation and with varying vertical wavelengths. One oscillation with a vertical wavelength of 6–7 km is apparent in both day–night and night–day profiles with nearly equal and opposite amplitudes detectable up to at least 45 km. Above this level the profiles become confused, although small oscillations with similar vertical wavelengths are apparent in places. Roy *et al.* (1972) noted during an intensive night-time series of Skua firings from the island of Gan in the Indian Ocean in the autumn of 1972, that this short vertical wavelength fluctuation was a common feature on comparison of dusk/dawn soundings, with typical amplitudes of 4 K in the 30 to 40 km region.

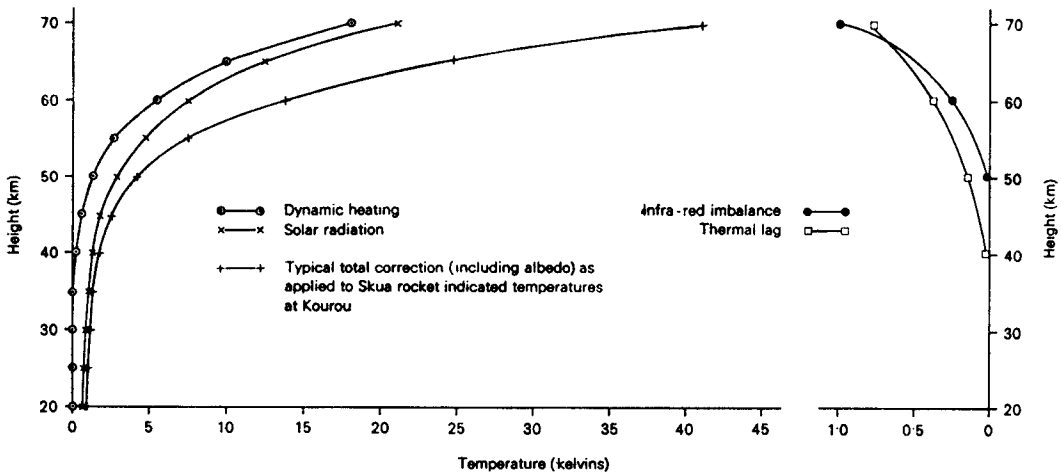


Figure 3. Principal corrections to temperature as applied to the Skua system. The curves on the left of the diagram (dynamic and solar radiation correction) are subtracted from the indicated temperature and those on the right (infra-red imbalance and thermal lag corrections) are added.

Individual daily mean temperature profiles are shown in Figure 4, together with the total period of day and night appropriate to each sounding. Some modification with time of the general profile shape is evident although the consistency of the major oscillation is reassuring. On each ascent the number of rockets making the mean profiles is indicated; the Loki Dart plot for night–day (21st) is included solely for the sake of continuity. Figure 5 shows the difference between mean profiles of day- and night-time zonal and meridional wind components. Reversal of westerly flow aloft to easterly flow below 41 km is well marked. Consistency between rocket systems seems good despite the use of two different retardation devices (two because the British Skua and the French Arcas employ parachutes with similar fall characteristics). Once again time difference between soundings may well account for much of the variation between profiles from the three rockets. Differences between day and night are clearly seen on both zonal and meridional component profiles, with positive and negative changes occurring at similar heights, displaying the marked oscillatory characteristic once again. Night profiles of meridional components exhibit very well-pronounced oscillations with vertical wavelengths between 5 and 7 km at 30 km, increasing to around 11 km above 42 km with a corresponding sudden increase in amplitude. Day-time profiles show similar fluctuations around 30 km but generally in antiphase with the night observations. Above 42 km large vertical wavelengths appear non-existent and the 5 to 7 km oscillation persists to at least 60 km. Discrepancy occurs between Skua results and the others above 60 km because momentum imparted by the rocket to the parachute is still present. The other rocket systems liberate their payloads at much higher altitude and therefore are affected by this bias to a lesser degree.

It was noted from the Gan observations of 1972 that short-time-period oscillations of meridional components over a period of 1 to 2 hours were a regular feature during the night and would presumably occur during the day, although no such observations were made in day-time during that experiment. Similar fluctuations appear to be also present in the Kourou observations and may well account for much of the difference between meridional component profiles. Again, however, the slightly different time of day or night involved for each pair of soundings is an equally important factor.

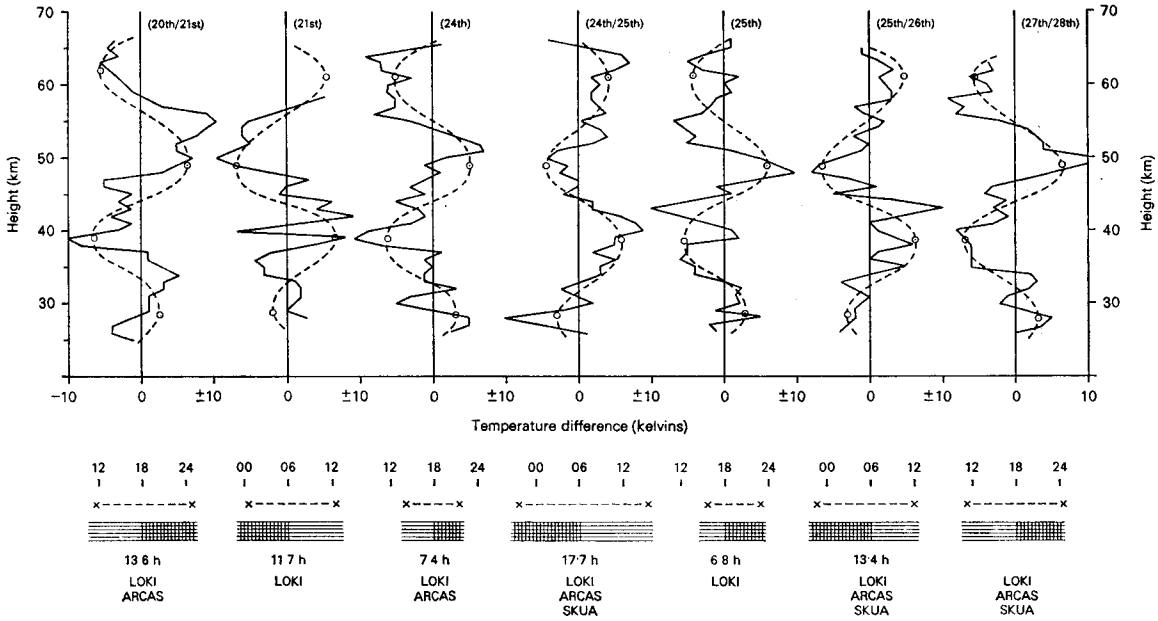


Figure 4. Individual daily mean diurnal variation of temperature. Dotted curves are simplified sine waves, constructed by eye with maximum amplitudes and constant height nodes taken from Figure 7 (a).

Figure 6 displays the actual diurnal variation with height of the data used in Figure 5, and, once more, a pronounced sinusoidal oscillation is apparent in the zonal component plots with vertical wavelength of around 18 km and an amplitude of 7 or 8 m s^{-1}. The similarity to temperature variation curves (Figure 2) is most striking, even to the superimposition of a 6–7 km vertical wavelength oscillation. Meridional component variations, on the other hand, do not show any large oscillatory characteristics; however, the 6–7 km wavelength appears to be present, at least up to 45 km. Above this level profiles become very confused, with many small wavelengths present, but a generally positive bias is present on the night-to-day periods and a negative between day and night.

Mean temperature and wind variations from the combination of the three systems appear in Figure 7 by way of a summary. From the foregoing results it would appear that the amplitudes and vertical wavelengths of the main oscillations in temperature and zonal wind component seem closely related, especially in the 25–55 km region of the stratosphere, with a change of 1 degree apparently corresponding to a variation of around 1 m s^{-1} in zonal wind component. The amplitude of zonal component oscillation is seen to increase with height, a result to be expected if energy dissipation with height is assumed to be negligible. This rate of increase is inversely proportional to the square root of the density of the environment although modification through absorption in critical layers (sudden changes in lapse rate) can occur.

Taking the 6–7 km oscillation up to a height of, say, 52 km there seems to be generally negative correlation between meridional and zonal components and with temperature variation. Above this level, meridional components appear quite independent of changes occurring in the other two parameters. The characteristic of the main oscillation generally agrees with that predicted by tidal theory developed by Lindzen (1967) which shows that for a dominant diurnal oscillation, vertical wavelengths

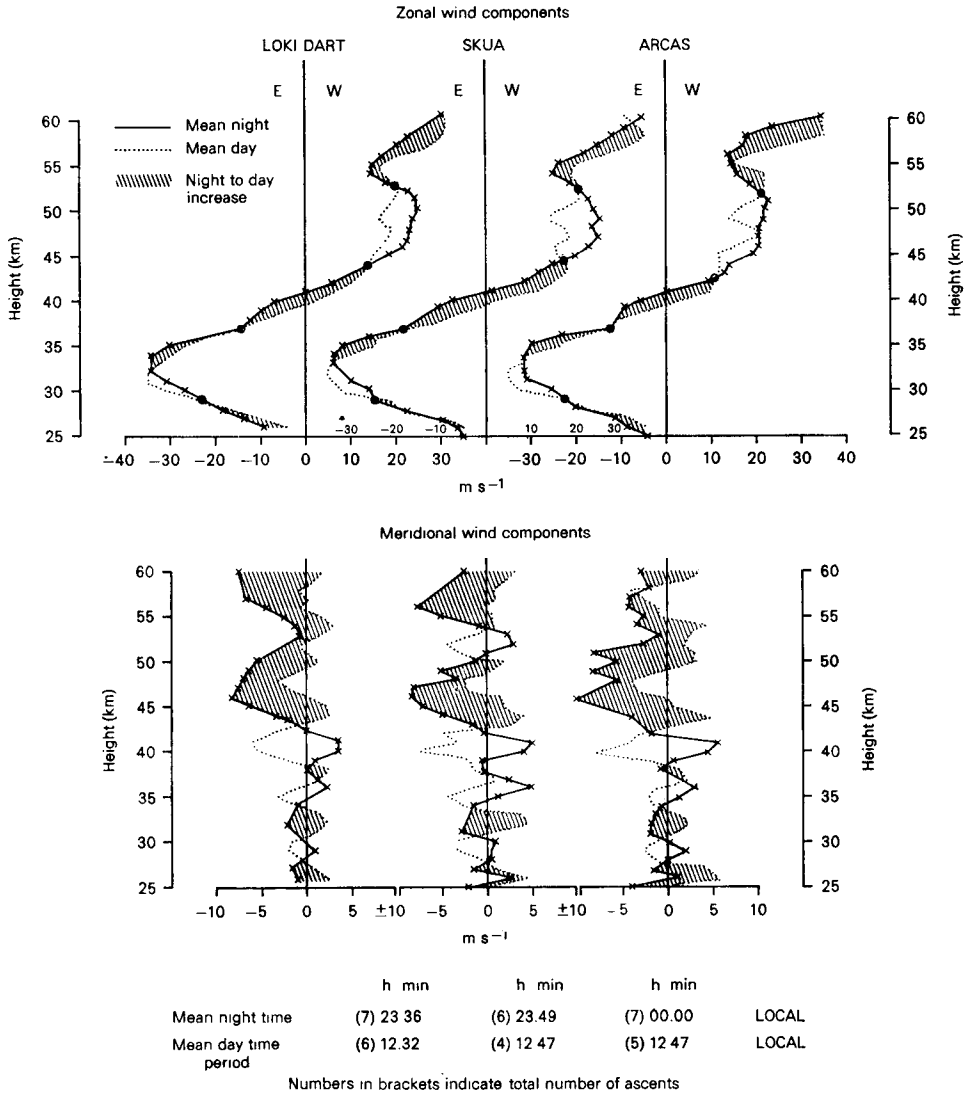


Figure 5. Differences between mean day and night profiles of zonal and meridional wind components (three rocket systems).

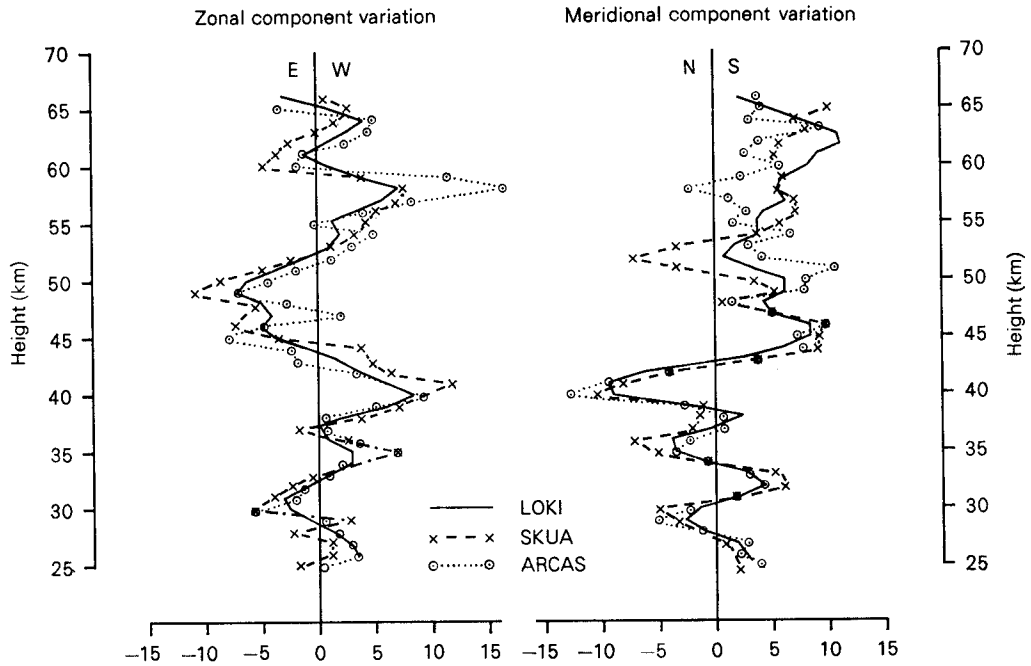


Figure 6. Variation with height of diurnal changes in zonal and meridional wind components (night-to-day increase). Components are in m s^{-1}.

very similar to those present here would be expected, with large variation in amplitude and phase occurring with height. Detection of a diurnal downward progression in the height of the oscillation, also predicted by this theory, is not possible because of the large time differences between night and day observations. The Gan observations in 1972 did, however, show this downward progression in the oscillation of both temperature and zonal wind component variation between 40 and 60 km during the 10 hour period from 1900 to 0500 local time. Any assessment of the length of the oscillation time period is obviously affected by the frequency of observations defining that oscillation. In this case the nearly equal magnitudes of the variation (amplitude) in temperature and zonal wind during night to day and day to following night imply that a diurnal mode is dominant. Let us consider a simplified sine wave oscillation (constructed by eye) in temperature variation with height with maximum amplitudes at the heights and times indicated in Figure 7 (dotted curve) with nodes at constant height level. If this oscillation is now superimposed on the daily curves of Figure 2 (dotted curves), suitably modified to take account of the time intervals between night and day observations, then the resulting oscillation has amplitudes similar to those of the actual profiles (ignoring small-scale fluctuations). If a semi-diurnal oscillation were present as the main mode then the magnitude of the amplitudes indicated in the profiles for the 24th and 25th in Figure 2 (7·4 and 6·8 hours observation periods repectively) would suggest a very small amplitude for the profiles of, say, the 20th/21st and 27th/28th (13·6 and 12·6 hours duration between observations). It follows further that since the 12–13 hour period amplitude is only slightly greater than that of the 6–7 hour period, temperature change with time is not uniform and the largest rates of change appear to occur near the start and end of the periods under observation. The change

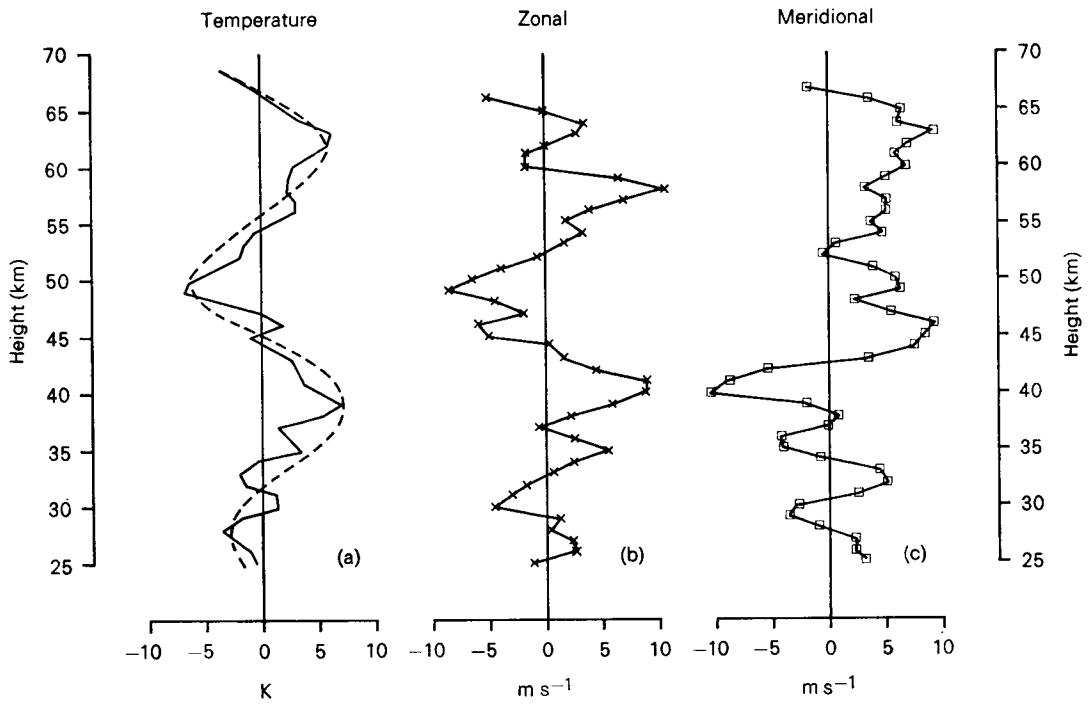


Figure 7. Mean temperature and wind variations from the three rocket systems (night-to-day increase). Dotted curve in (a) is a simplified sine wave constructed by eye.

indicated on the profiles for day to night (25th and 27th/28th) certainly suggests an irregular rate of change, with largest values near to local midnight. A similar rate of change occurred on all three night-firing sequences at Gan with largest temperature changes occurring in the layers above 35 km between 2200 and 2300 local time.

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International Conference on Climate and History, University of East Anglia, 8–14 July 1979

By D. E. Parker

(Meteorological Office, Bracknell)

About 250 participants from over 30 countries gathered for a week at Norwich for the International Conference on Climate and History. The subject matter, presented in over 50 half-hour lectures and 15 shorter contributions, aimed to cover the whole range of disciplines involved in the study of past and present climate and of the complex interactions between climate and human activity.

The conference began with review papers on scientific and historical methods of climate reconstruction, including a summary of past climates. The first paper, a concise presentation of the use of tree-ring evidence, set the tone of the conference: one of marked progress but of even more marked uncertainty because of the complex relationships involved; the reconstructions of weather in the U.S.A., from tree rings for years with meteorological data, are far removed from the observed meteorological conditions although positively correlated with them. The review of glaciological evidence of recent climatic change stressed the problems of timing—for instance, how long does it take for a glacial moraine to become able to support the growth of trees? The summary of pollen analysis laid strong emphasis on the complexity of climate–vegetable interactions, for even at the present time species are not in equilibrium with climate; in Finland certain trees are becoming established progressively farther north at a rate far in excess of what might be expected from current changes in climate. Isotopic data, too, can give ambiguous results; oxygen isotope ratios in ice-caps depend not only on the temperature but also on the atmospheric circulation when the snow falls.

Having been enlightened as to the problems of scientific analysis of past climate via proxy data, the conference was then presented with a summary of the problems of analysis of historical records. A warning was issued concerning the use of syntheses of ancient records by recent compilers, as these volumes may contain many errors and omissions; however, at the end of the conference it was admitted that without these compilations our knowledge would be much scantier than it is. There are also linguistic and cultural problems with old records. What do 'drought', 'haze', 'fog' mean? When exactly is summer? (Many writers probably mean May to July—August and September were 'autumn' (German *Herbst*, cf. English harvest)). Has an author used over-exaggerated language? A small group was formed to begin a study of these problems by means of a 'content analysis'.

Notwithstanding these difficulties, some speakers appeared well satisfied with the quality of their data, notably Dr C. Pfister of Switzerland, who has been carefully sifting Swiss documentary evidence for 1525 to 1825, using only primary sources (i.e. original reports) covering for example crops, vine yields and freezing of lakes. Later in the conference Professor G. Manley presented similar work for Britain for 1550 to 1658.

The review of archaeological evidence for climatic change further stressed the difficulties of interpretation and the complexities of cultural response to climatic variations, but it included an interesting presentation of the relics of past Eskimo settlements on islands in the Canadian Arctic, with tentative results which agreed with the generally accepted warmth 1000 and 4000 years ago.

Professor H. H. Lamb's lecture illustrated the spatial and temporal variability of climate, mainly for the benefit of participants from the historical disciplines. A temperature anomaly chart for summer

1976 made the many British delegates realize that our hot summer was very localized. It was estimated that the coldest year in England since 1700 would, other factors being equal, have generated twice the fuel demand for the warmest year, the corresponding factor for decades being 1·2.

All the review papers except that on isotopes were published beforehand by the Climatic Research Unit of the University of East Anglia, though some authors modified their views considerably for presentation.

Most of the remaining papers were on specific geographical and disciplinary areas. Early instrumental data have been used to produce maps for China and north-west Europe, and have been applied to studies of the Rocky Mountains, Hudson Bay, Australia, and New Zealand. Documentary evidence has been employed in studies of rainfall over Africa, India, China and parts of South America. The inadequacy of many of the records was made very clear.

Tax relief records were used to infer the 17th/18th century climatic conditions in Norway, and the authors of this work deduced that the 'Little Ice Age' period of cold climate began a century later in Norway than in the Alps. Some participants questioned the relationship of tax relief to climate, but the suggestion that the colder climates were not contemporaneous in different regions was supported by tree-ring studies indicating warmth in the 'Little Ice Age' in the western U.S.A. By the end of the conference Professor Lamb summarized the general feelings on the 'Little Ice Age' very well by saying that the term was a convenient one for a certain period of climatic behaviour and must not be taken literally to mean increased coolness everywhere.

Great difficulty was often found, and great ingenuity shown, in attempts to relate population statistics (births, marriages, deaths, migrations) to climate. Even the link between climate and agriculture was found to be complex, and to deduce climate from agricultural statistics, study of marginally viable locations was necessary. Reports of harvests were shown to be influenced dramatically by the political mood of the day: when Edward III came to the throne in 1327 there was a sudden improvement in the reported harvests!

A variety of papers illustrated the specific effects of floods, droughts and severe frosts on communities or on specific events in past centuries. The coverage was virtually world-wide. The influence of such catastrophes was, yet again, very dependent on the cultural and political environment and on agricultural practices. Some past societies may have been too inflexible to withstand the vagaries of climate. An important concept was that the impacts of climate are affected by the popular perception of climatic variation—thus the notion that 'rain follows the plough' westward in the U.S.A. helped to set the stage for the dust-bowl of the 1930s.

Several papers tackled the subject of variability of rainfall and temperature, the resulting effects on man in modern times and the need to take steps to reduce our vulnerability to such climatic variability. Included among these were two presentations by delegates from the Meteorological Office. Mr D. M. Houghton discussed the effects of the recent severe weather in Britain, which he estimated cost the nation in the region of £500 million, £300 million of this for extra fuel consumed, mostly for space heating. The cost to the National Bus Company was £12 million. A 'misery index' defined on the basis of combinations of cold and wet half-months showed that January up to mid-June 1979 was the most miserable such period for over 150 years. But a table of extreme cold, warm, wet and dry months and seasons in the last 20 years was used to illustrate that in recent years the extremes experienced have not exceeded expectations based on the past three centuries. Mr D. E. Parker used 5-year mean charts of 1000–500 mb thickness over most of the northern hemisphere to illustrate spatial and temporal variability since the early 1950s, and to show that regional temperature variations depended on circulation changes, and almost cancelled when averaged over the hemisphere. It was also shown that the reduced average strength since 1940 of the North Atlantic surface westerlies represented an increase in frequency

of occurrence of the weak westerly mode at the expense of the strong westerly mode in a bimodal distribution.

The possible effect of advancing technology on our vulnerability to climate was well illustrated by Professor M. J. Bowden by a qualitative diagram showing how the geographical spread of the burden of drought occurring in the Great Plains of the U.S.A. was changing with time: in the 1890s effects were locally large and globally negligible, at present they were evenly spread, and in the future they might well be locally small but globally severe; that is to say local catastrophes may be ameliorated by technology at a cost to the global system. Also our demand for a higher standard of living may have made us more susceptible to long-term climatic changes even though we have gained some skill in relieving the effects of short-term disasters.

It was stressed that the climatic historian needs to verify the influence of climate on past events by using known causal relationships to 'retrodict' the events. Mere coincidence or correlation of climatic and human events is insufficient. A correlation does not constitute a cause or even prove that a common cause underlies both phenomena. The notion that a correlation does constitute a cause (based on Hume's philosophical concept of a cause as being merely man's interpretation of observed correlation) was found by the writer of this report to be the basis of one participant's approach to the problem of solar influences (sunspots etc.) on the climate. In fields of research where information is lacking or only qualitative, 'results' are often largely the product of researchers' scientific philosophy. Some of the papers presented concerning earlier historical times were largely speculation.

The conference served its purpose well in stimulating thought and promoting interdisciplinary and international co-operation in the field of climate and history. The scope was so broad that several participants proposed that conferences be arranged on particular aspects or on particular eras of history. This added weight to the conclusions of the conference that there is still a very long way to go.

Notes and news

Dr K. A. Browning, F.R.S.—Special merit promotion to Deputy Chief Scientific Officer

It is a pleasure to record that Dr Keith Browning has been granted promotion to Deputy Chief Scientific Officer under the scheme which permits the promotion of scientists of exceptional ability without consequential change in their administrative responsibilities. Dr Browning was appointed to the Meteorological Office in 1966 as a Principal Research Fellow and was given his first individual merit promotion to Senior Principal Scientific Officer in 1972. From the beginning of his career in the Office he was given the task of leading the joint Office/RSRE radar meteorology group at Malvern. This was a field of research in which Dr Browning had already made significant contributions, since studying under the late Professor Ludlam at Imperial College, and at the Air Force Cambridge Research Laboratories in the U.S.A.

Under Dr Browning's guidance the Malvern group have made impressive progress in the application of radar to the investigation of precipitation processes in both frontal and shower clouds and in the interpretation of radar echoes received from clear skies, and about 50 scientific papers have resulted from this work. Dr Browning is now applying his expertise to the practical problem of improving our capability of forecasting precipitation and wind over short periods ahead of up to 6 to 12 hours. The Malvern group is at present involved in setting up a mini-network of precipitation radars covering much of England, and in processing their output so that the rainfall can be presented in an easily assimilated form in real time on a TV screen in such a way that the colour of each 5 km sided square positioned on a map of England represents the rainfall at that location. Similar arrangements have been made to process infra-red satellite data from Meteosat. In this case the different colours represent different cloudtop -temperatures. With the establishment of this new experimental data base we look forward to the optimization of its use for short-period forecasting which will be the main thrust of Dr Browning's work over the next few years. P.G.

Dr F. B. Smith—Transfer to special merit Senior Principal Scientific Officer

Dr F. B. Smith, at present Assistant Director of the Boundary Layer Branch, has been awarded a transfer to the ranks of the individual merit Senior Principal Scientific Officers. At a time when world-wide concern is focused on environmental problems, many of them concerned with the diffusion of pollutants in the atmosphere, it is fitting that Dr Smith should be released from all administrative burdens so that he can concentrate on furthering the understanding of the meteorological factors controlling the spread and deposition of material emitted from the earth's surface.

Dr Smith joined the Office in 1956 after gaining his Ph.D. in Professor Lighthill's Mathematics Department at Manchester University and spent his early career, like so many world authorities on boundary-layer problems, with the Office's research group at CDEE Porton. In 1974 he was promoted to Senior Principal Scientific Officer and subsequent to that time has progressively taken on the role in the field of atmospheric diffusion once held with such distinction by Dr F. Pasquill.

The Meteorological Office is indeed fortunate to have a scientist with Dr Smith's flair, recently illustrated in his treatment of the long-range transport of sulphur compounds, for achieving down-to-earth practical results when tackling problems in an area which can be a minefield of mathematical complexity.

P.G.

European Association of Remote Sensing Laboratories (Council of Europe)

A postgraduate Summer School on Remote Sensing in Meteorology, Oceanography and Hydrology will be held at the University of Dundee from 1 to 20 September 1980.

The school is intended for postgraduates and other research workers in the fields of meteorology, oceanography, and hydrology and for teachers in these subjects in institutions of tertiary education who are contemplating introducing more material on remote sensing into the courses within their own institutions.

The course will be concerned with the processing and interpretation of remote sensing data. The topics covered will include:

Data Collection Systems
Digital Methods and Processing
Principles of Image Interpretation
Pattern Recognition
Geometric Registration of Images and Maps
Methods of Motion Display and Change Detection
Sea Surface Temperatures and Fronts
Winds and Currents
Atmospheric Motions
Meteorological Models
Hydrology
Pollution Monitoring.

Some bursaries may be available to assist students to attend.

Further particulars and registration/application forms can be obtained from:

Professor A. P. Cracknell,
Carnegie Laboratory of Physics,
University of Dundee,
DUNDEE DD1 4HN,
Scotland, U.K.

Climatic variations: facts and causes, Erice, Sicily, 9–21 March 1980

The title of the Erice School 'Climatic Variations: Facts, Causes' (see Vol. 108, page 252) has been changed into 'Nato Advanced Study Institute on: Climatic Variations and Variability: Facts and Theories'.

The Australian climatic environment. E. Linacre and J. Hobbs.

The above-named book, which was reviewed on p. 159 of the *Meteorological Magazine* for May 1979, has now been published in the United Kingdom by John Wiley & Sons Ltd, Chichester, Sussex, and is on sale at £11.35.

Meteorological Magazine—increase in price

As from January 1980 the price of an issue of the *Meteorological Magazine* will be £1.60 and the annual subscription will be £20.82 including postage.

THE METEOROLOGICAL MAGAZINE

No. 1289 December 1979 Vol. 108

CONTENTS

Page

Aircraft measurements in the GARP Atlantic Tropical Experiment. J. M. Nicholls 349

Diurnal variations of temperature and wind in the 25–65 kilometre region of the equatorial stratosphere. G. C. Bridge 367

International Conference on Climate and History, University of East Anglia, 8–14 July 1979. D. E. Parker 376

Notes and news

Dr K. A. Browning, F.R.S.—Special merit promotion to Deputy Chief Scientific Officer .. 379
Dr F. B. Smith—Transfer to special merit Senior Principal Scientific Officer 379
European Association of Remote Sensing Laboratories (Council of Europe) 380
Climatic variations: facts and causes, Erice, Sicily, 9–21 March 1980—change of title .. 380
The Australian climatic environment. E. Linacre and J. Hobbs 380
Meteorological Magazine—increase in price 380

NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ, and marked 'For Meteorological Magazine'.

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

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